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**A STUDY ON THE CONTROL OF
GROUNDWATER HAZARD
GAYS RIVER MINE**

VOLUME VII

**NUMERICAL INVESTIGATION OF
GROUNDWATER INFLOW
GAYS RIVER MINE, NOVA SCOTIA**

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Fracflow Consultants Inc.

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MICROMEDIA

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OF GROUNDWATER INFLOW,
GAYS RIVER MINE, N.E.**

**R. MacLeod, G.G. Bursey, J.E. Gale
FRACFLOW CONSULTANTS INC.**

FINAL REPORT

Submitted to:

**Westminer Canada Ltd., and
Canada Centre for Minerals and Energy Technology (CANMET)**

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Abstract

The three-dimensional, finite element computer code CFEST was used to carry out preliminary numerical modelling of the groundwater flow system surrounding the Gays River mine, on both regional and local scales. The large-region model (111 km²) was used to simulate a low-to-average mine dewatering rate of 4197 USgpm and it provided the boundary head conditions for the small-region model. The small-region model (16.8 km²) was used to examine mine inflows in detail, for both low-to-average flow and high flow periods of the year.

Total mine inflow in the low-to-average flow simulation was 4017 USgpm. The distribution of hydraulic heads around the mine, which were a reasonable approximation of measured heads, and computed pathlines suggest that regional groundwater flow is responsible for the baseflow component of about 4000 USgpm to the mine. A saturated flood plain along Gays River and increased surface infiltration were simulated in order to determine how much inflow they contributed during peak mine inflows. However, total mine inflow increased to only 4098 USgpm when these features were included.

This preliminary, three-dimensional numerical modelling has clearly shown that the initial characterization of the mine hydrogeology, in earlier studies conducted at Gays River, is incomplete. However, the model has been constructed so that additional hydrogeological data from ongoing studies can be incorporated into the model. It is recommended that the existing model be modified to reflect the additional data that has been collected on the distribution of overburden materials, solution cavities and sinkholes to determine (1) their role on the magnitude and seasonal variations in mine inflows and (2) if remedial actions would be effective. Secondly, storage coefficient data for the different geological materials should be used in the model to run transient simulations, which would provide a better picture of the sources of water in the short-term. Finally, groundwater flow paths calculated by the model provide an effective means of comparing the hydraulic data with the chemical and isotopic data. This work should be done in order to constrain the interpretation of the groundwater sources and pathways.

Table of Contents

	Page
Abstract	ii
Executive Summary	v
List Of Figures	ix
1.0 INTRODUCTION	1-1
1.1 Background	1-1
1.2 Scope and Objectives	1-1
1.3 Setting	1-2
1.3.1 Location And Climate	1-2
1.3.2 Geology	1-3
1.3.3 Hydrogeology	1-4
2.0 NUMERICAL MODELLING APPROACH AND DATA	2-1
2.1 Introduction	2-1
2.2 Modelling Approach for Gays River	2-1
2.3 Hydrologic Data	2-2
2.3.1 Methods Of Determination	2-2
2.3.2 Data Sources And Calculations	2-3
3.0 SIMULATION OF REGIONAL GROUNDWATER FLOW	3-1
3.1 Finite Element Mesh And Boundary Conditions	3-1
3.2 Model Input Parameters	3-2
3.3 Model Calibration	3-4
3.4 Results	3-5
4.0 DETAILED MINE SIMULATION	4-1
4.1 Finite Element Mesh And Boundary Conditions	4-1
4.2 Model Input Parameters	4-1
4.3 Model Calibration	4-2
4.4 Model Results	4-4
4.5 Pathway Predictions	4-5
5.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS	5-1

6.0 ACKNOWLEDGMENTS

6-1

7.0 REFERENCES

7-1

APPENDIX A Hydrologic Data Calculations

A-1

APPENDIX B Large Scale Maps

B-1

Executive Summary

Westminer Canada Ltd. and CANMET devised and implemented a three phased project for the "Control of Groundwater Hazard, Gays River Mine, Nova Scotia". As part of the Phase III activities, Fracflow Consultants have developed a baseline model of groundwater flow to assess the recharge mechanisms, the sources of water and the pathways of groundwater flow to the Gays River Mine. The groundwater flow system surrounding the Gays River mine was investigated at both the large (111 km²) and small (16.8 km²) scales of study using the three-dimensional, finite element, computer program CFEST. The large-region model was used to determine the influence of mine dewatering on regional groundwater flow and to identify the boundary head conditions for the small-region model. This modelling was performed under steady-state conditions.

The three-dimensional finite element mesh of the large-region model incorporated the main hydrogeological features of the area. The size and shape of each element and the nodal point locations were chosen so that the actual topography, bedrock distributions and mine workings were represented as closely as possible. The flow model was subdivided into 10 layers to represent the third dimension (i.e. depth). Most layers in the model were input as flat surfaces to coincide with specific mine levels. Four 20 m thick layers represented the 480-460, 460-440, 440-420 and 420-400 m mine levels. Two layers, sandwiched between the overburden (layer 1) and the 480-460 m mine level (Layer 4), were given variable thickness to account for surface relief.

On the scale of the large-region model, the trench sediments could be ignored and most bedrock and layer boundaries defined as straight-line segments. Meguma Group rocks of varying thickness underlie the entire flow model to its base at -500 m depth. Overlying evaporites of the Windsor Group were modelled to shallow, intermediate and deep levels across the region. Shallow evaporites ranged beneath the overburden to the 400 m mine level, while intermediate and deep evaporites ranged below the mine workings to depths of 325 and 250 m, respectively. Windsor Group carbonates were placed in contact with the Meguma around the mine area and were modelled to a maximum depth at the 440 m mine level. The surface layer of the large-region model represented overburden with a constant thickness of 15 m. Hydraulic properties for each material were the same regardless of where the material occurs in the large-region model.

The water table during pre-mining conditions was simulated by a series of fixed heads across the entire surface of the model. Dewatering by the mine and the resulting cone of depression were simulated by adjusting the boundary conditions in the vicinity of the mine. These adjustments entailed assigning values of fixed elevation head (pressure head = 0 m, or atmospheric pressure) to nodes that outlined the mine workings, using a trial and error

approach to define the areal extent of the cone of depression at surface, and applying a constant rate of recharge to all surface elements within the cone of depression. The drawdown cone was assumed to be elliptical and encompassed the full extent of the trench in the NE-SW direction (total area = 1.01 km²). A constant surface recharge of 1.308×10^{-9} m/s per m² was assigned to the surface elements within the cone of depression, equal to 6 percent of the difference between mean annual precipitation and evapotranspiration. Initially, a total mine flux of 5189 USgpm was computed for the large-region model. The model was calibrated to reflect an average dewatering rate of between 4000-4500 USgpm.

Calibration of the large-region model consisted of expanding the cone of depression to 4.79 km² in surface area and reducing the hydraulic conductivity of the carbonates and the evaporites. After these adjustments, a total mine flux of 4197 USgpm was computed for the mine case simulation. The computed heads and gradients were found to be comparable to general site conditions and the model was considered acceptable for providing the external boundary conditions for the small-region model.

The small-region model was developed with the same approach used to construct the large-region model, but a greater number of nodes and elements were used to represent details of the mine area. Particular attention was given to defining the mine excavations and the geometry of the trench and denoting sampling locations being used by other sub-contractors in parallel studies. The small-region model was subdivided into ten layers to represent the third dimension (i.e. depth), using the same layering sequence as in the large-region model. Unlike the large-region model, the small-region model accounts for the presence of glacial fluvial sands and gravels and the trench sediments. The trench has been represented by a band of 5 metre wide elements. The slope of the trench was approximated by assigning trench properties to adjoining elements in a step-like manner, where necessary.

The small-region model was calibrated for low-to-average mine inflows (about 4000 USgpm) by proportionally reducing the hydraulic conductivities of the different geological materials. Hydraulic conductivities finally assigned to the geological materials in the small-region model are as follows:

MATERIAL	K_h (m/s)	K_v (m/s)
Overburden	7.2×10^{-08}	7.2×10^{-09}
Alluvium	7.2×10^{-08}	7.2×10^{-09}
Sand	7.2×10^{-04}	3.6×10^{-04}
Trench	3.6×10^{-06}	1.8×10^{-06}
Evaporites	2.4×10^{-06}	1.2×10^{-06}
Carbonates	1.2×10^{-06}	6.0×10^{-07}
Quartzites	3.6×10^{-08}	1.8×10^{-08}
High K Zone	3.0×10^{-05}	1.5×10^{-05}

Following calibration, a total mine flux of 4017 USgpm was computed. The small-region model showed less drawdown around the mine area at surface than shown by the large-region model. The small-region model is probably more realistic of actual conditions since the rock mass above the mine is partially to fully saturated (i.e. perched water table). Hydraulic heads computed for the 480 m and 440 m mine levels showed that the zone of influence of the mine is significant at depth and the cone of depression was slightly elongated, following the outline of the trench and the mine workings. Contour plots of hydraulic heads indicated that water is pulled into the mine from regional sources.

Mine inflows were then simulated for high recharge conditions. The surface recharge was doubled to 2.616×10^{-9} m/s per m^2 and the nodes adjacent to Gays River were assigned fixed heads to simulate the saturated flood plain. The results showed a small increase in mine flux of only 81 USgpm compared with the previous small-region model simulation, which is probably because the model did not include sinkholes in Gays River as discrete features and also because the permeability data provided for the flood plain materials may have been too low. The saturated flood plain did have an obvious effect on the distribution of heads and gradients at surface, despite a total mine flux of only 4098 USgpm.

Eleven pathlines were calculated by the small-region model for starting points in the simulated mine and at the model surface. Pathlines were calculated from known points in the mine with large inflows, including the 118 sump area and the 808 cross-cut area, as well as from possible sources of surface water such as Moshers Quarry and sites of known sinkholes in Gays River. Pathlines were found to vary greatly in direction and length, ranging from straight lines of only a few metres in length to curved lines that were kilometres long. At the 426 m mine level in the 808 cross-cut area, the model suggested that water was derived from a regional source located about 2 km west of the mine area, while at the 405 m mine level near the 118 sump, a component of groundwater inflow is probably derived from a recharge point several kilometres to the north.

Simulations with the small-region model suggest that regional groundwater flow is responsible for the baseflow component of about 4000 USgpm to the mine. The small increase in mine flux after simulating a saturated flood plain and increased surface infiltration supports the view that sinkholes in Gays River and(or) the flood plain must channel surface water to the mine during periods of high flow. This preliminary, three-dimensional numerical modelling has clearly shown that the initial characterization of the mine hydrogeology, in earlier studies conducted at Gays River, is incomplete. However, the model has been constructed so that additional hydrogeological data from ongoing studies can be incorporated into the model.

It is recommended that the existing model be modified to reflect the additional data that has been collected on the distribution of overburden materials, solution cavities and sinkholes to determine (1) their role on the magnitude and seasonal variations in mine inflows and (2) if remedial actions would be effective. Secondly, storage coefficient data for the different geological materials should be used in the model to run transient simulations, which would provide a better picture of the sources of water in the short-term. Finally, groundwater flow paths calculated by the model provide an effective means of comparing the hydraulic data with the chemical and isotopic data. This work should be done in order to constrain the interpretation of the groundwater sources and pathways.

List Of Figures

		Page
Figure 1-1	Location map showing the limits of the large-region model, selected highways and towns, and an outline of the trench.	1-7
Figure 3-1	(a) Finite element mesh for the large-region groundwater flow model (b) and associated well-logs that describe the layering sequences.	3-7
Figure 3-2	Contour maps of (a) the original topography, as digitized from 1:50,000 scale maps, and (b) the topographic surface created by computer smoothing.	3-9
Figure 3-3	Plan view of the nodal points spread across the surface of the large-region model, and a three-dimensional view of the water table simulated for pre-mining conditions.	3-10
Figure 3-4	Assumed areal extent of the cone of depression for initial large-region model runs (1) and the final cone of depression (2) used to represent conditions at Gays River.	3-11
Figure 3-5	Configuration of the water table as modelled by the large-region model for mining conditions.	3-12
Figure 3-6	Comparison of the water table at the mine site for both pre-mining and mining conditions, as computed by the large-region model.	3-13
Figure 3-7	Comparison of hydraulic heads at the 440 level in the mine vicinity, for both pre-mining and mining conditions, as computed by the large-region model.	3-14
Figure 4-1	(a) Finite element mesh for the small-large region, groundwater flow model (b) and associated well logs that describe the layering sequences.	4-7
Figure 4-2	Location of sand units.	4-9

Figure 4-3	Location of cross-sections used to determine material property assignments for the small-region model.	4-10
Figure 4-4	Configuration of the water table as modelled by the small-region model without the simulated flood plain.	4-11
Figure 4-5	Hydraulic head distribution at the 480 m level as computed by the small region model without the simulated flood plain.	4-12
Figure 4-6	Hydraulic head distribution at the 440 m level as computed by the small-region model without the simulated flood plain.	4-13
Figure 4-7	Configuration of the water table as modelled by the small-region model with the simulated flood plain.	4-14
Figure 4-8	Comparison of water table at the mine site as computed by the small-region model with and without the simulated flood plain.	4-15
Figure 4-9	Plan view of 11 pathlines computed for the small-region model and cross-section views of pathlines 1 to 4.	4-16
Figure A-1	Pump test data for DW-3 (Dames and Moore, 1980) plotted on semi-log and log-log graphs.	A-7
Figure A-2	Observation well data collected for H-2, H-3, and H-4 during the DW-3 pump test (Dames and Moore, 1980), plotted on semi-log diagrams.	A-8
Figure A-3	Observation well data collected for OW-1 and OW-1A during the DW-3 pump test (Dames and Moore, 1980), plotted on semi-log diagrams.	A-9
Figure A-4	Recovery data collected for wells DW-1, DW-2, DW-3 and H-4 during the mine close-out period in 1982 (Leggette, Brashears & Graham, 1983), plotted on semi-log diagrams.	A-10

- Figure A-5 Recovery data collected for wells ETW-1, ETW-2, ETW-3 and OW-1A during the mine close-out period in 1982 (Leggette, Brashears & Graham, 1983), plotted on semi-log diagrams. A-11
- Figure A-6 Recovery data collected for wells OW-2 and OW-3 during the mine close-out period in 1982 (Leggette, Brashears & Graham, 1983), plotted on semi-log diagrams. A-12
- Figure A-7 Recovery data collected for DW-1, DW-2, OW-3 and ETW-4 after pump tests at each well (Lamb, 1990). A-13

1.0 INTRODUCTION

1.1 Background

Mining at Gays River, Nova Scotia, is complex and often hazardous as a result of being unable to effectively control mine-water inflows. The current mine operator, Westminer Canada Ltd., and the scientific authority supporting the remediation efforts, CANMET, devised and implemented a three-phased project for the "Control of Groundwater Hazard, Gays River Mine, Nova Scotia".

Phase I of this project involved the assimilation of existing hydrogeological data gathered over the history of mine operations, and the compilation of this information into a summary report (Meyer, 1990). This report was an important first step toward interpreting data contained in the large volume of mine operators' and consultants' reports in a common framework. Phase II activities comprised a panel discussion between various consultants, Westminer and CANMET, that were aimed at formulating practical work strategies to best address the problems of dewatering. Phase III involved the implementation of the Phase II recommendations and Fracflow Consultants was assigned the task of developing a numerical groundwater flow model for the Gays River Mine site. This report is focused on the methodology, development and results of this modelling effort.

1.2 Scope and Objectives

Three-dimensional, numerical, groundwater flow modelling is an important "tool" for investigating the hydrogeology of an area, especially in complex environments such as at the Gays River mine site. The focus of this study was to generate a baseline model of groundwater flow to assess the recharge mechanisms, the sources of water and the pathways of groundwater flow to the Gays River Mine.

The groundwater flow system surrounding the Gays River mine was investigated at both the large and small scales of study, using a three-dimensional finite element computer program known as the Coupled Fluid, Energy, and Solute Transport code (CFEST; Gupta et al., 1986). A nested model approach was taken here whereby the large-region flow model was prepared and examined before modelling groundwater flow at the mine site in detail. This method was necessary because groundwater flow systems typically extend over large areas and, therefore, the regional controls on hydraulic heads must be reflected in the small-region model.

The large-region model was used to investigate the groundwater flow system for both pre-mining and mining conditions. The natural flow system that existed prior to mining operations was modelled as a

reference for measuring the change in groundwater flow patterns in response to mining and dewatering. Average mine dewatering rates were simulated to provide the boundary conditions for the small-region model.

The focus of the small-region model was to characterize the flow system around the mine site in detail. Two basic scenarios were examined to simulate the different hydraulic head and flux conditions at the mine site for both dry to average and wet periods. Low to average flow conditions were modelled for a dry flood plain in Gays River and mine discharge of approximately 4000 USgpm. Wet conditions were modelled for peak flow in Gays River, a saturated flood plain and higher than average infiltration around the mine area.

Results from this modelling work provided insight into the three-dimensional distribution of hydraulic heads, the flow pathways and the locations of recharge and discharge areas around the mine site. These flow models can provide Westminer Canada with a means to test the effect of possible control and remediation measures on reducing mine inflows. However, these results are considered to be preliminary because a limited amount of quantitative information was available for numerical input. The incorporation of additional information into the model, as it becomes available, will help constrain present interpretations.

1.3 Setting

1.3.1 Location and Climate

Gays River, Nova Scotia, is located approximately 70 km NE of Halifax, at the border between Colchester and Halifax Counties. The Gays River Mine, which produces lead and zinc from a carbonate hosted deposit, lies on the south side of both the village of Gays River and the river itself. The watershed surrounding the mine is modelled over a surface area of 111 km² (Figure 1-1).

Previous descriptions of the climate at the mine site are reported as averaged data collected at Halifax International Airport (19 km SW) and Upper Stewiacke (40 km NE). The climate is extremely variable because of mixed continental and maritime weather patterns at Gays River. The mean annual temperature is 5.9 °C (Dames and Moore, 1976), mean annual precipitation is 1250 mm (Meyer, 1990), and yearly evapotranspiration is estimated to be 560 mm (Dames and Moore, 1976).

1.3.2 Geology

The geology of the Gays River area is discussed in numerous reports. A review of the information contained in Akande and Zentilli (1984), Giles and Boehner (1982), Lin (1970), McKee and Hannon (1982) and Pinder (1968) is presented here.

Gays River lies along the crest of a NE-SW trending anticline that divides the Shubenacadie Basin to the Northwest from the Musquodoboit Basin to the Southeast. The study area is located between two major fault zones; the E-W trending Black Brook Fault to the north, and the NE-SW trending Chaswood Fault to the south.

The oldest rocks at Gays River comprise a Cambro-Ordovician sequence of quartzites and slates of the Meguma Group, which form the basement complex of the region. These bedrock units are metamorphosed to the greenschist facies, tightly folded into anticlines and synclines, and are intruded by granitic plutons of Devonian age. The Meguma Group is subdivided into the lower Goldenville Formation and a conformably overlying Halifax Formation. The Goldenville formation forms the major bedrock unit in the study area, composed mainly of thickly bedded quartzitic greywacke and quartzite showing minor slate along bedding planes. The Halifax Formation on the other hand, is predominantly slate containing a minor amount of quartzite. These rocks have a prominent slaty cleavage and are dissected by several joint systems that often show mineral infilling on fracture planes.

An angular unconformity separates the Meguma Group from overlying polymictic conglomerates and conglomeratic sandstones of the Horton Group. This Group is of late Tournaisian age and consists of the Coldstream, Horton Bluff and Cheverie Formations. These formations are not a prominent part of the local geology in and around the mine site.

The Windsor Group, which disconformably overlies the Horton Group rocks, is an important part of the geological framework of the mine setting. The Windsor Group is segregated into 8 different formations, but only two of the formations, of middle Visean age, are prominent in Gays River; the lower Gays River Formation and the upper Carrolls Corner Formation. The Gays River Formation is represented by fossiliferous deposits of dolostone and minor limestone, which are faulted and host to the Gays River lead-zinc orebodies. The Carrolls Corner Formation is a sequence of marine evaporites that include gypsum, anhydrite, halite, minor potash, and minor interbeds of dolostone and mudstone.

The evaporites and carbonates are apparently in shear contact. The contact on the NW limb of the Gays River anticlinal structure was eroded and filled with what is now believed to be Early Cretaceous mud, sand, silty sand, gravel and gypsum fragments. These sediments are over-consolidated and define a long and sinuous

structure referred to as the "trench". Both the bedrock and trench sediments are buried under 20 to 40 m of glacial till, which is locally cut by glacial-fluvial sands and gravels.

1.3.3 Hydrogeology

The hydrogeology of a region is influenced by a number of different factors and one of the most basic characteristics is climate. High precipitation and low evapotranspiration in the Gays River watershed couple to leave a substantial amount of water for surface runoff, of which a small percentage is groundwater recharge. Average surface runoff and recharge components in the watershed, calculated as the difference between mean annual precipitation and evapotranspiration, are estimated to total 690 mm. The specific nature of the resulting surface water and groundwater flow in this area is determined by factors such as the topography, vegetation type and cover, land use, abundance of lakes and streams, and geology.

The Gays River watershed is characterized by a gently rolling landscape, having a maximum relief of 170 m, an extensive cover of deciduous forest, a small population, and local agricultural land development. The topography is the driving force behind groundwater flow and the hills and valleys can be generally classified as regions of groundwater recharge and discharge, respectively. The highest hills in the NE and SW corners of the Gays River watershed will act as important recharge environments. The topographic gradients are estimated to vary between 0.015 and 0.15 in this watershed and probably generate flow paths, from recharge to discharge points, that are kilometres long and 100's of metres deep.

Lakes, ponds and rivers are sparsely distributed throughout the watershed, but several lakes of hydrological significance are present. The main drainage features in the mine vicinity include Gays River, South Branch Gays River, the nearby Annand Bog and Brook, the tailings/polishing pond and sinkholes. The average flow in Gays River in 1973 and 1974 averaged approximately $6.9 \text{ m}^3/\text{s}$ (110,000 USgpm), ranging between 0.09 (1500 USgpm) and $17.0 \text{ m}^3/\text{s}$ (270000 USgpm) (Dames and Moore, 1974). Flows in excess of $11.9 \text{ m}^3/\text{sec}$ (188,000 USgpm) spill over the banks of Gays River and into the surrounding floodplain (McKee and Hannon, 1982).

The surficial geology at Gays River is dominated by glacial clay-till deposits, glacial-fluvial sands and gravels, and river alluvium along Gays River. The clay till is the predominant overburden material at Gays River and it is often thickest beneath hills, varying in thickness from 20 to 40 m (Leggette, Brashears & Graham, 1982). Dames and Moore (1980) noted that the glacial till can reach a thickness of up to 91 m. Consequently, it is not

surprising that there is little evidence of the various rock units outcropping at surface.

The clay till has a low permeability and is considered to be an aquiclude where present, creating confined or semi-confined aquifer conditions at depth. The poorly conductive till maintains a perched groundwater system above it; one that is associated with the floodplain of Gays River (Dames and Moore, 1980) and one that is probably isolated from the deeper groundwater system, except in the presence of sinkholes. The clay till is locally cut by glacial-fluvial sands and gravels that sometimes rest directly in contact with the bedrock. These deposits often have a permeability capable of yielding large volumes of water at rates of up to 200 gpm (Dames and Moore, 1974) to individual wells.

Beneath the glacial deposits lies the Cretaceous surficial material infilling the trench; the contact between these materials is either poorly defined or unrecognizable. The trench formed as a result of uplift and erosion along the evaporite-carbonate contact. The evaporites were denuded meters to 10's of meters back from the carbonates because of their susceptibility to mechanical and chemical erosion. A karstic topography has formed at the trench contact and along the upper surface of the evaporites, showing open and sand-filled caverns, pits, sinkholes and solution channels (Dames and Moore, 1974; McKee and Hannon, 1982): one of the few surface exposures of karstic gypsum is observed at Taylors Pond. The more resistant carbonates were also eroded, but less severely, producing a zone of highly porous leached bedrock. The mineralization is usually found at the carbonate-trench contact.

Trench sediments comprise a hard-packed mixture of mud, silty sand and gravel that is impervious on the whole, although water-bearing, fossiliferous "worm hole" pipes and gravel interbeds are locally observed (Jacques, Whitford and Associates, 1990). It is possible that significant groundwater flow occurs in the deeper portions of the trench where the sediments are coarse and suspected to be part of the so-called Bedrock Aquifer (Meyer, 1990). Large groundwater and sediment inflows can occur when the mine excavations intersect saturated and permeable zones within the trench. The quantity of groundwater flow through the trench sediments, however, has remained undetermined.

Significant groundwater flows that are associated with the trench seem to be channelled along its contacts with the evaporites and the carbonates (McKee and Hannon, 1982). Along the evaporite-trench contact, sand-filled karstic features in the evaporites are probably important. Because of the large permeability contrast between this high conductivity zone and the low permeability trench sediments, high hydrostatic pressures are sometimes observed where the trench borders the mine excavations.

The evaporites, carbonates and quartzite typically yield very low volumes of water unless their permeabilities are enhanced by the presence of fractures, joints or solution cavities. The basement rocks of the Meguma Group are extensively faulted and jointed. Underground mapping showed steeply-dipping faults that strike N-S, E-W and N60°W, which can be traced through the overlying carbonates. Two prominent joint sets have orientations of 330°, dipping 70°W, and 085°, dipping 50°W (Akande and Zentilli, 1984).

The main body of the evaporite deposits is described as a poor or low yield aquifer (Leggette, Brashears & Graham, 1982). Evidence of its widespread low permeability is provided by a visual assessment of the small volumes of groundwater discharge into the National Gypsum Quarry, low yield domestic water wells, and excellent core recoveries in the main body of the formation (Jacques, Whitford and Associates, 1990). Even limestone aquifers that show development of solution cavities do not necessarily produce high water yields (Lin, 1970). In general, the average groundwater yields from the bedrock are less than 20 gpm and are commonly less than 10 gpm (Dames and Moore, 1974; Nova Scotia Department of the Environment, 1991).

Gays River Large-Region Model Area

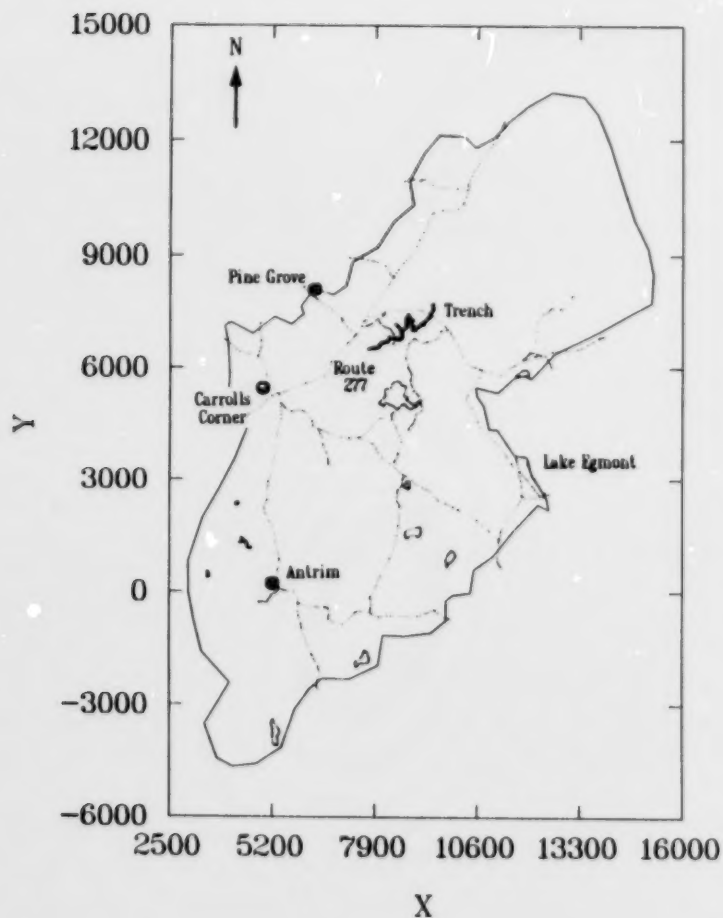


Figure 1-1 Location map showing the limits of the large-region model, selected highways and towns, and trench outline. X and Y scales are in metres and referenced to mine coordinates.

2.0 NUMERICAL MODELLING APPROACH AND DATA

2.1 Introduction

The purpose of this study was to determine the three-dimensional configuration of the groundwater flow system, in the fractured bedrock and overburden, at the Gays River Mine site. The three-dimensional, finite element computer code, CFEST, was used in this study. CFEST was designed as a "tool" to complement hydrogeological studies by providing data to assist with a more quantitative understanding of the complex physical (and chemical) interactions associated with natural flow systems.

CFEST can represent a study area as a series of layers of discrete nodes and elements with defined hydrologic parameters. Finite elements are created at the model surface by connecting individual nodes, thereby sub-dividing the surface into an irregular grid that approximates the irregular boundaries of a particular hydrogeological system. A vertical borehole is simulated at each nodal point to intersect the different layers of materials and variable thicknesses known to exist at specific locations. A series of three-dimensional elements are then created by connecting the nodes on the top and bottom of each layer to produce a three-dimensional model of the flow region. The spacing of model nodes and layer thicknesses are varied as required. Closely spaced nodal points and thin layers can be used in areas where greater changes in hydraulic heads are expected, while a relatively sparse distribution of nodes and thicker layers can be used for areas where small changes in hydraulic head are anticipated.

2.2 Modelling Approach for Gays River

The direction and magnitude of groundwater flow to the Gays River mine is determined by the large groundwater sink created by mine dewatering, the topography of the water table, the location of surface water bodies, and the distribution of hydraulic conductivity for different geological materials. Groundwater flow models of the study site were constructed by numerically accounting for these and other significant hydrogeological features in the area.

Two finite element models were constructed and used to investigate the groundwater flow system on both the local and regional scales. The large-region model covered an area of approximately 111 km² and the small-region model, which was centered on the mine, covered an area of approximately 16.8 km². Model boundaries were drawn along streams, rivers, lakes and topographic drainage divides (see discussion in Chapters 3 and 4).

The hydraulic data assigned to the model were specified to

represent the properties of the carbonates, evaporites, and the average effect of sinkholes and solution cavities, as well as the quartzite, trench sediments, glacial till, glacial-fluvial deposits, and river and flood-plain deposits. The spacing of nodes, elements, and layers were varied to achieve more detail in and around the mine workings. The finite element method enabled the irregular boundaries of this hydrogeological system to be closely approximated by an irregular grid.

2.3 Hydrologic Data

2.3.1 Methods of Determination

Several types of data were used to estimate the hydraulic conductivities of the various rock and overburden types at Gays River. Grain-size analyses, water-level recovery tests in observation wells, and pump test data compiled from the available mine and consultants' reports were analyzed.

Several different formulations were available to relate the soil texture to hydraulic conductivity (see Freeze and Cherry, 1979). A simple and useful expression used here is Hazen's power law,

$$K = A \cdot (d_{10})^2$$

where, A is an empirical coefficient and d_{10} is the grain-size diameter, below which 10% of the sample grains are smaller and 90% are larger. When d_{10} is expressed in mm, A is equal to 1.0 and K is calculated in units of cm/s. Hazen's approximation was compared to Masch and Denny's (1966) empirical relations for several sample calculations, and the results suggested that the Hazen K values are probably good estimates to within an order of magnitude.

Data collected from water-level recovery tests were analyzed using the method of Hvorslev (1951; see also Fetter, 1988). Recovery time is plotted against the log of the drawdown to determine the slope of the recovery curve. The equation used to calculate conductivity is as follows:

$$K = \frac{d^2 \cdot \ln \cdot [(2 \cdot m \cdot L) / D]}{8 \cdot L \cdot (t_2 - t_1)} \cdot \ln \frac{H_1}{H_2}$$

where, D = diameter at the well screen,
 d = diameter of the standpipe,
 L = length of the screen,
 H_1 = head at time t_1 ,
 H_2 = head at time t_2 ,
 m = ratio of horizontal to vertical conductivity (assumed to be 1 here).

Results from this type of analysis are probably reasonable and accurate to within an order of magnitude (see Appendix A).

Constant-rate pumping tests conducted in geological formations can provide some of the most reliable information for transmissivity (T = hydraulic conductivity multiplied by aquifer thickness) and storativity (S) calculations. The Jacob straight-line method (Driscoll, 1987; Fetter, 1988) was used to analyze pump test data here (see Appendix A).

2.3.2 Data Sources and Calculations

There is little hydraulic conductivity data available in the existing mine reports, as well as little information available for the calculation of hydraulic conductivities, for the suite of geological materials that exist in the Gays River area. Many of the existing reports and other data were reviewed during the site visit and the available, relevant data were subsequently extracted and analyzed (Table 2-1; Appendix A). Drilled wells were categorized as representatives of evaporite and carbonate rocks, as a simplification. These wells were categorized on the basis of the proportion of rock type reported in each well and the expected locations of the major water inflows (Jacques, Whitford and Associates Ltd., 1990; Meyer, 1990).

The conductivities of the glacial-fluvial sands and gravels, clay till, and trench sediments in the mine vicinity have been estimated from grain-size analyses (Dames and Moore, 1974; Jacques, Whitford and Associates, 1977; 1990). Variability in the conductivity of sand and gravel deposits have been accounted for at the regional scale by using pump test data from the Musquodoboit River valley (Pinder, 1968; Lin, 1970) and Antigonish (Trescott et al., 1970) areas of Nova Scotia. The sands and gravels show a high range of conductivities, with K values varying between 10^{-3} to 10^{-4} m/s; the close agreement between calculations for pump test and grain-size data (Table 2-1) support the validity of Hazen's power-law relation. The trench sediments are estimated to have a hydraulic conductivity in the order of 10^{-6} m/s. The clay till has a low permeability, with K values between 10^{-6} and 10^{-8} m/s.

Pump test and recovery data were available to evaluate the transmissivities of the Windsor Group evaporites and carbonates (see Appendix A). Data from one of the few pump tests conducted at the mine site (Dames and Moore, 1980) were analyzed by Meyer (1990). His estimates of T are 370-520 m²/day between DW-3 and OW-1a, and 600-840 m²/day between DW-3 and H-4, which suggests that T is highest in the E-W direction, rather than in the N-S direction. This would be reasonable considering that the ore zone trends approximately N60°E and that the high permeability zones along the trench-bedrock contacts parallel the ore. However, a re-evaluation of Dames and Moore's data here (Appendix A) suggests that the later

time-drawdown data is more reliable, owing to the constant slope of the data points over much longer periods of time. T is found to be 400 m²/day between OW-1A and DW-3, and 352 m²/day between H-4 and DW-3. Because pumping rates were not recorded during the test, the uncertainties in these calculations are considerable. In the absence of other data, it is therefore assumed that the bedrock has a constant transmissivity in the horizontal plane.

The conductivities of the evaporites and carbonates were investigated further by analyzing the water-level recovery data during the mine close-out period of August 12 to October 27, 1982 (Leggette, Brashears & Graham, 1983; see Appendix A). An analogy was made between conducting a short-term, constant-rate pump test in a well and conducting a long-term, constant-rate pump test by dewatering the mined excavations. Assuming an average mine discharge of 4000 USgpm, log time was plotted against recovery data for the ETW, OW, and DW series of holes, as well as for H-4. The two estimates of transmissivity for both H-4 and OW-1A, calculated from the pump test (Dames and Moore, 1980) and mine close-out recovery (Leggette, Brashears & Graham, 1982) data, are in close agreement (Table 2-1), which supports the validity of analyzing the mine close-out data in this manner. The calculated conductivities show the evaporites and carbonates to be poor conductors of groundwater on the average. These data probably do not reflect the maximum conductivities possible in the zones affected by leaching and dissolution.

The storage coefficients estimated for OW-1A, using both the pump test (Dames and Moore, 1980) and mine close-out recovery data (Leggette, Brashears & Graham, 1982), differ significantly. It is possible that the higher S calculated from the earlier pump test is indicative of semi-confined conditions, while the lower S obtained for the mine close-out period of 1982 suggests an unconfined condition. The transition from the semi-confined to unconfined conditions may reflect the further development of the underground workings.

The hydrologic properties of the Meguma shales and quartzites have been examined using pump test data from Halifax County (Gale, 1973). These rocks have very low conductivities and are probably only significant water producers in heavily jointed or fractured areas.

Table 2-1 Estimated hydraulic conductivities and storativities for major geological materials in the Gays River area.

Data Source		Range in K (m/s)		Range in S	
<u>Glacial-Fluvial Sand and Gravel:</u>					
Pump ^a		3.6E-4	1.6E-3	4.3E-4	7.0E-2
Grain Size ^b		2.0E-4	4.0E-3		
Grain size ^d		1.7E-4	4.4E-4		
<u>Trench Sediments</u>					
Grain Size ^c		5.0E-9	1.0E-8		
Grain size ^c		4.0E-4	3.2E-4		
Grain size ⁱ		1.4E-6	7.2E-5		
<u>Clay Till</u>					
Grain Size ^b		1.0E-8	2.0E-6		
<u>Evaporites</u>					
OW-1A ^{g,e}	Pump/Recovery	2.1E-4	7.7E-4	2.0E-4	4.3E-2
OW-2 ^g	Recovery	1.4E-4		9.6E-3	
OW-3 ^{f,g}	Recovery	9.9E-8	4.1E-4	6.5E-3	
DW-2 ^{f,g}	Recovery	3.9E-4	3.0E-6	1.5E-2	
DW-3 ^g	Recovery	2.2E-5		1.5E-2	
ETW-1 ^g	Recovery	4.3E-5		1.1E-2	
ETW-2 ^g	Recovery	3.4E-5		6.0E-3	
<u>Carbonates</u>					
H-4 ^{e,g}	Pump/Recovery	4.9E-5	1.6E-4	7.6E-4	1.4E-2
DW-1 ^{f,g}	Recovery	2.8E-7	1.8E-5	5.3E-2	
<u>Quartzites and Slates</u>					
^h	Pump	6.4E-9	2.2E-7		
<u>Data Sources</u>					
a	Trescott et al. (1970), Pinder (1968), Lin (1970)				
b	Dames and Moore (1974)				
c,d	Jacques, Whitford and Associates (1990;1977)				
e	Dames and Moore (1980)				
f,i	Lamb (1990;1991)				
g	Leggette, Brashears & Graham (1983)				
h	Gale (1973)				

3.0 SIMULATION OF REGIONAL GROUNDWATER FLOW

3.1 Finite Element Mesh And Boundary Conditions

Groundwater flow systems normally extend over large regions. The purpose, then, of the large-region groundwater flow model is to determine both the influence that mine dewatering is having on regional groundwater flow as well as to identify any regional sources of mine inflow that may be important. Furthermore, an evaluation of regional flow patterns is necessary during investigations in small areas of interest, in order that the hydraulic head controls on the local groundwater flow can be established. Specifically, the large-region model computes the hydraulic heads that are assigned to the boundary nodes of the more detailed small-region model; a nested-model approach.

The finite element mesh of the large-region model covered a surface area of 111 km², as shown in Figure 3-1a. This mesh incorporated the basic hydrogeological features of the area, which included the various surface water bodies such as Gays River, Lake Egmont, and the tailings/polishing pond, as well as the Windsor and Meguma Group geology and the mine excavations. The size and shape of each element and the nodal point locations were chosen so that the actual topography, bedrock relations and mine workings were represented as closely as possible. Nodes and elements were more closely spaced in and around the mine workings to provide for greater detail in this area.

Developing this hydrogeological model from the available data base required a number of simplifications and assumptions in order to prepare the available data for numerical input. A simplified, digital representation of the ground surface for the large-region model was generated by digitizing surface contours from 1:50,000 scale topographic maps and then estimating elevation using a regular grid pattern. Original map contours and the computer generated surface are shown in Figure 3-2 for comparison. Geological relations in the model were simplified by ignoring the existence of the trench sediments in the mine area and by recognizing most bedrock and layer boundaries as straight-line contacts. In addition, the Gays River mine and its surrounding area were modelled as a steady-state flow system.

Several important assumptions were also made while the large-region model was being constructed. By locating the boundaries of this model along streams, rivers, lakes and topographic/drainage divides, it was assumed that fixed head boundary conditions could be assigned to all of the model boundaries. It is also assumed that the surface topography was a subdued reflection of the water table. Consequently, the depth to the water table across the model was approximated by applying a smoothing function to the digital topographic surface, while the elevations of points of known head

(rivers, lakes, and ponds) were maintained. This effectively lowered the surface in high areas and elevated it in depressed areas, usually by several metres at each location. This subdued surface became an approximation for the water table. Figure 3-3 shows the three-dimensional configuration of the smoothed water table. Regional water table highs are shown to the northeast and southwest of the mine. These highs are important features that drive groundwater flow toward the mine, which is located in the flat-area near the center of the model.

The water table for pre-mining conditions was simulated as a series of fixed heads at nodes across the entire surface of the model. Boundary conditions in the vicinity of the mine were adjusted in order to create a drawdown cone and simulate dewatering from the mine. First, the nodes that outline the mine workings were assigned a fixed value of elevation head only (pressure head = 0 m, or atmospheric pressure). Then, to enable the model to compute a drawdown cone at depth, the areal extent of this cone was assumed to be known at surface and a recharge rate was applied to all elements at the surface.

The drawdown cone was estimated (Figure 3-4) to encompass the full extent of the trench in the NE-SW direction, while making its dimension in the NW-SE direction one element beyond those that approximate the mine workings (total area = 1.01 km^2): the area of recharge was expanded during calibration of the model, as described in Section 3.3. Surface nodes within the assumed cone of depression remained free, meaning the hydraulic heads were not fixed at those nodes and were free to vary so that drawdown could be calculated. A constant surface recharge of $1.308 \times 10^{-9} \text{ m/s}$ per m^2 was assigned to the surface elements within the cone of depression, equal to 6 percent of the difference between mean annual precipitation and evapotranspiration.

Since recharge rates are typically between 7 to 15% in good ground conditions (Gale et al., 1987), a value of 6% for the average overburden in the Gays River area is believed to be a reasonable approximation. All other nodes outside the zone influenced by dewatering maintain fixed head values representative of water table conditions. The model calculates a flux, equal to the recharge necessary to maintain the fixed heads at surface, for these nodes at steady-state.

3.2 Model Input Parameters

The large-region groundwater flow model was subdivided into a total of 10 layers (Figure 3-1b). The surface layer of the large-region model consisted of overburden, which was considered to be glacial till. The mean depth of overburden across the region was determined using water well records (Nova Scotia Department of the Environment, 1991) for the communities of Antrim (18 wells),

Carrolls Corner (16 wells), Cooks Brook (12 wells), Dutch Settlement (10 wells), East Milford (1 well), Gays River (15 wells), Lake Egmont (3 wells), Milford Station (117 wells), Pine Grove (67 wells) and Shubenacadie (28 wells). The average value calculated was 15 m.

Bedrock geology across the large-region model was based on 1:50,000 scale maps and cross-sections of the Shubenacadie and Musquodoboit Basins (Giles and Boehner, 1982). This model has simplified some of the geological relations however, by ignoring the existence of the trench sediments in the mine area and by creating most bedrock and layer boundaries as straight-line segments. Although CFEST was not restricted to such simplistic representations of layering, it was both meaningful and convenient to have created mostly flat layers in the model that coincided with specific mine levels. Four 20 m thick layers were defined by the 480-460, 460-440, 440-420, and 420-400 m mine levels. Two layers of variable thickness however, were sandwiched between layers 1 (overburden) and 4 (480-460 m mine levels) to account for the surface relief.

Meguma Group rocks of varying thickness underlaid the entire flow model to its base at the -500 m model level. Overlying evaporites of the Windsor Group were modelled as shallow, intermediate, and deep evaporites across the region. The depth of shallow evaporites ranged beneath the overburden to the 400 m mine level, while intermediate and deep evaporites ranged to the 325 and 250 m model levels, respectively. Windsor Group carbonates were in contact with the Meguma around the Gays River mine area, being modelled to a maximum depth of the 440 m mine level.

The hydraulic properties for each material were the same regardless of where the material occurs in the large-region model. The initial approximations for hydraulic conductivity were within the range of values presented in Table 3.1, but other qualitative data were also considered. The evaporites for example, were expected to have a significantly higher conductivity than the carbonates, owing to solution cavities and other karstic features in the former rock sequence. As a result, the carbonates were given a lower K value than the mean of the values in Table 3.1.

When assigning hydraulic conductivities to layers in the flow model, it is necessary to differentiate between values for the vertical and horizontal directions. Although there is no such information available for materials in the Gays River area, fractured bedrock is typically anisotropic. The overburden is also expected to be anisotropic. The horizontal bands of silt and clay within the till probably support a significantly greater conductivity in the horizontal direction. In the model, bedrock was assigned a K_h/K_v of 2 and the clay till was given a K_h/K_v of 10. These input data are summarized in Table 3.1 (see also Appendix A).

Table 3.1 Hydraulic conductivities initially assigned to geological materials of the large-region model.

MATERIAL	K_h (m/s)	K_v (m/s)
Overburden	1×10^{-07}	1×10^{-08}
Evaporites	1×10^{-05}	5×10^{-06}
Carbonates	5×10^{-06}	2.5×10^{-06}
Quartzites	5×10^{-08}	2.5×10^{-08}

3.3 Model Calibration

The large-region model was used to simulate steady-state groundwater flow for both pre-mine and mining conditions. Pre-mining conditions were initially modelled to identify the natural flow system that existed prior to the mine operations and to measure the response of the flow system to mining and dewatering. A large-scale map of the simulated water table is provided in Appendix B.

The pre-mine groundwater flow model was adjusted and executed to simulate the effects of mining operations on the regional groundwater flow system. Essentially, the 53 nodes that were located on the mine workings were assigned fixed heads that equal elevation head (pressure head = 0; atmospheric pressure), and surface elements within the assumed cone of depression (total area = 1.01 km^2) were assigned a constant rate of recharge ($1.308 \times 10^{-9} \text{ m/s per m}^2$). To determine if the shape of the cone of depression was reasonable, initial model runs were performed for both the pre-mine and mine cases of the large-region model.

The difference in head values for all nodes bounding the cone of depression, for pre-mine and mine conditions, were examined at various depths. At the 440 m mine level, difference in drawdowns averaged 23 m for a range of values between 9 and 40 m. At this stage of calibration, the total mine flux computed for the large-region model was 5189 USgpm. Since this was supposed to reflect a mean annual dewatering rate, this mine flux was obviously too high. To achieve a more realistic mine flux of between 4000 and 4500 USgpm, the hydraulic conductivity of the carbonates and the evaporites were reduced (Table 3.2). The total mine flux was thereby lowered to 4324 USgpm, which is considered to be a reasonable figure.

Although the mine flux at this point was acceptable, the cone of depression was too small. Because this was a model of steady-state conditions, the difference in drawdowns at the boundary of the cone of depression should ideally be equal to 0. Therefore, the cone of

depression was expanded by another element (total area = 4.79 km²) on all sides to reduce this difference between the pre-mine and mine cases (Figure 3-4). This adjustment to the mine case reduced the average drawdown at the 440 m mine level for example, to an average of 12 m around the perimeter of the cone of depression, for a range of values from 4 to 20 m. The total flux computed for the mine case simulation after this adjustment was 4197 USgpm.

Table 3.2 Hydraulic conductivities finally assigned to geological materials of the large-region model.

MATERIAL	K_h (m/s)	K_v (m/s)
Overburden	1×10^{-07}	1×10^{-08}
Evaporites	3.3×10^{-06}	1.6×10^{-06}
Carbonates	1.6×10^{-06}	8.3×10^{-07}
Quartzites	5×10^{-08}	2.5×10^{-08}

Because the drawdown cone at Gays River is transient, varying in size in response to seasonal hydrological events, it probably never reaches the maximum extent defined for steady-state conditions. Therefore, the revised size and shape of the cone of depression (Figure 3-4) is believed to be a reasonable approximation of its true shape. The large-region model is believed to be a good representation of the hydrogeological features and conditions at Gays River and its surrounding area.

3.4 Results

Figure 3-5 illustrates the shape of the water table modelled in the mine case. The contours in the north-central part of the model area clearly show the cone of depression created by pumping from the mine. The influence of the mine operations on groundwater flow can be observed in detail by comparing the diagrams in each of Figures 3-6 and 3-7.

Figure 3-6 displays the water table configuration in the immediate mine area for both pre-mine and mine conditions. Generally weak hydraulic gradients are present in the absence of the Gays River mine and groundwater flow through the overburden is generally toward Gays River (note that the closed 515 m contour is an artifact of the sparse data points in that area). During mine operations, a steep cone of depression is simulated near the main zone of pumpage (118 sump), with the deepest drawdowns present at the 436 m mine level.

Figures 3-7 shows the hydraulic heads at the 440 m level of mine workings, for both pre-mine and mine conditions. Very weak hydraulic gradients are calculated at this depth for the case without the mine. For the mine case, a strong perturbation in the natural groundwater flow system is observed. Drawdowns below the 450 m mine level are observed just north and southwest of the 118 sump. These water levels are in good agreement with the July '91 water levels. The modelled centre of pumpage does not fall exactly over the 118 sump in this case, simply because the model nodes are spaced 10's of metres apart in the large-region model.

The total mine flux calculated by the large-region model is 4197 USgpm. Since this model is simulating steady-state groundwater flow on an average annual basis, we consider this to be a reasonable approximation considering that it is not possible to account for the detailed features in the mine area at this scale. The small-region model, however, does include many of the complexities of this hydrogeological system. The tight spacing of nodes and the small size of the elements in the small-region model more accurately describe the low permeability trench sediments and the high K zones in the leached carbonate and karstic gypsum (Chapter 4).

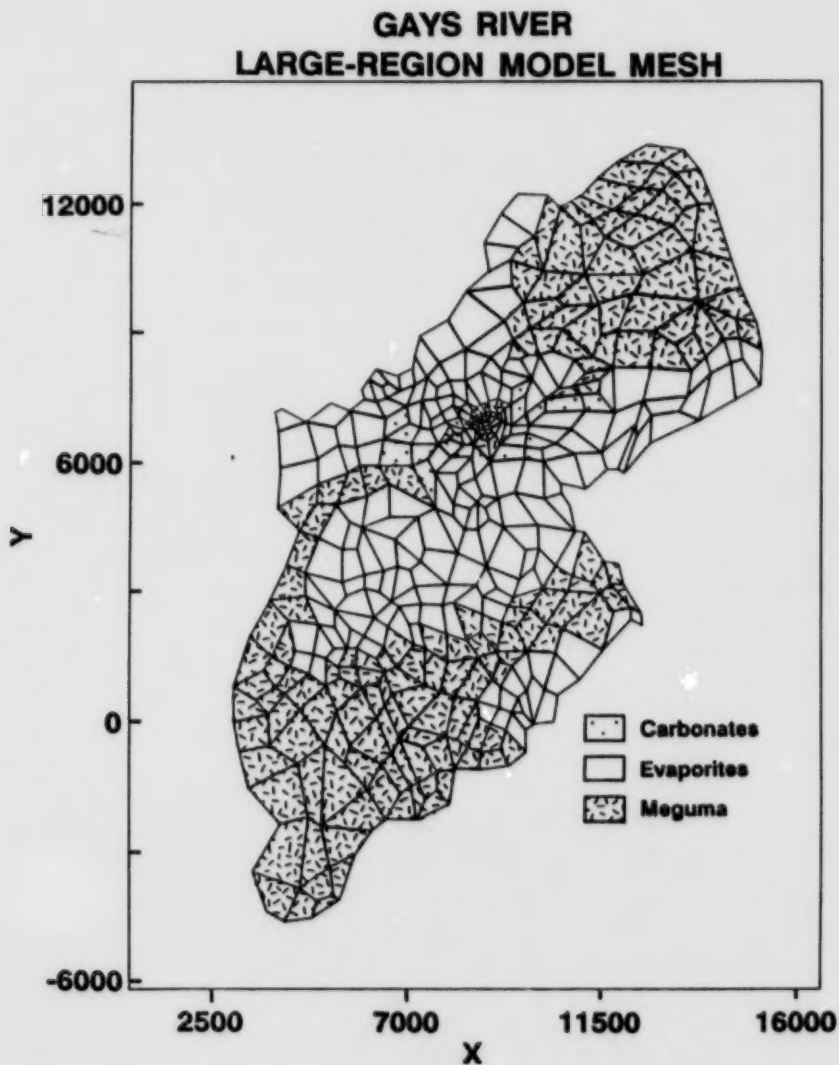


Figure 3-1 (a) Finite element mesh for the large-region groundwater flow model (above) and (b) associated well-logs that describe the layering sequences (next).

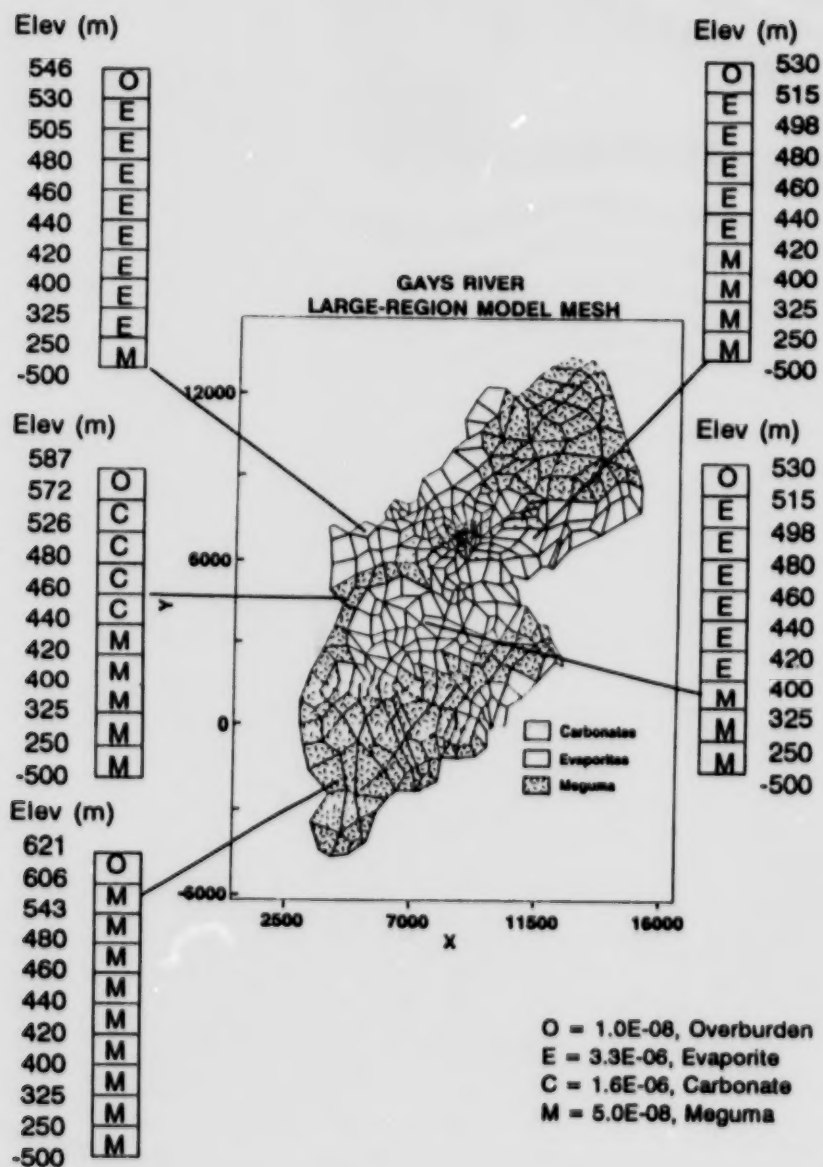


Figure 3-1 Continued.

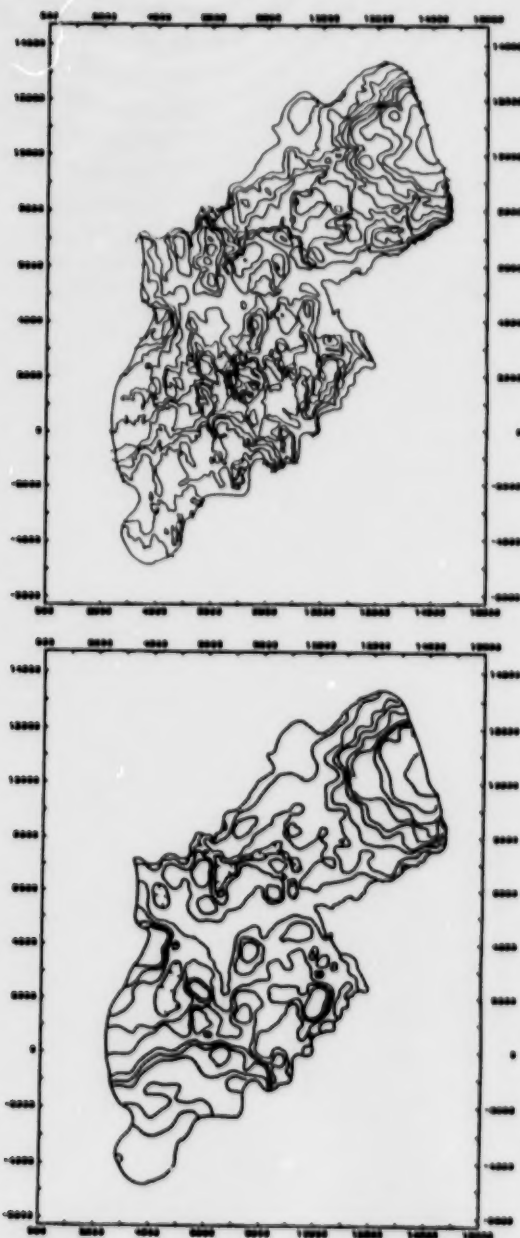


Figure 3-2

Contour maps of (a) the original topography, as digitized from 1:50,000 scale maps, and (b) the topographic surface created by computer smoothing.

Gays River Regional Flow Model

Water Table Surface (smoothed 3-D)

Nodal points (Plan)

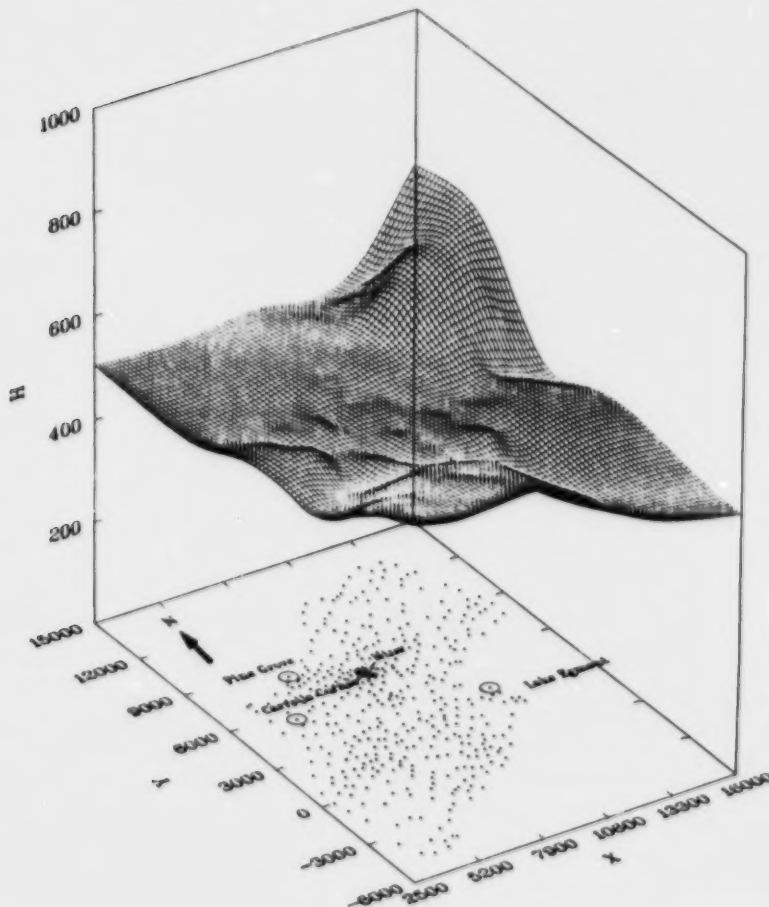


Figure 3-3

Plan view of the nodal points spread across the surface of the large-region model, and a three-dimensional view of the water table simulated for pre-mining conditions.

Gays River Regional Flow Model

Cones Of Depression

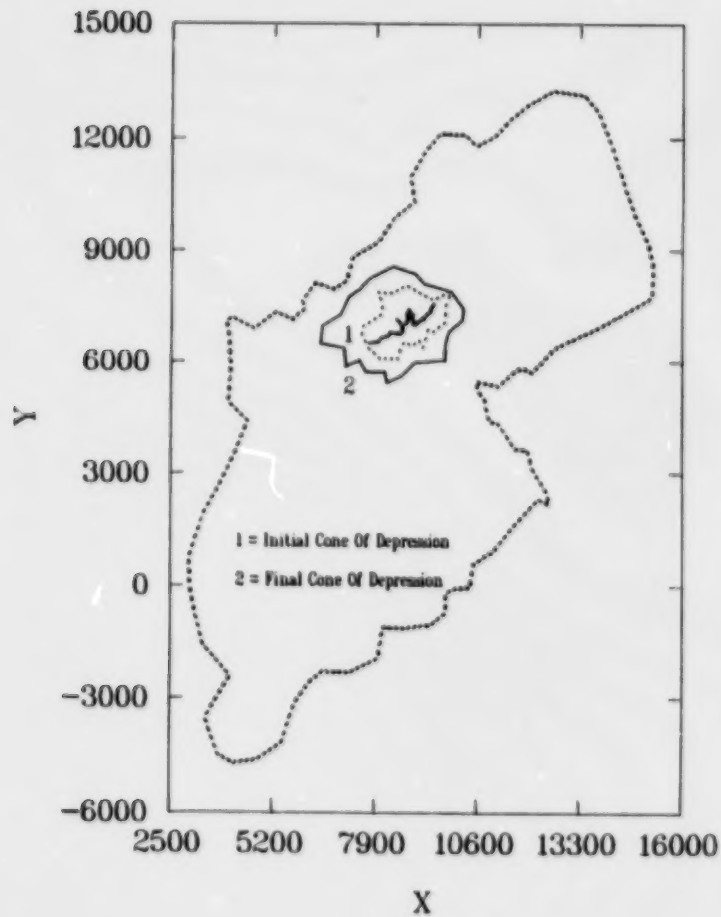


Figure 3-4

Assumed areal extent of the cone of depression for initial large-region model runs (1) and the final cone of depression (2) used to represent conditions at Gays river.

Gays River Regional Flow Model

Smoothed Water Table

Mine Case

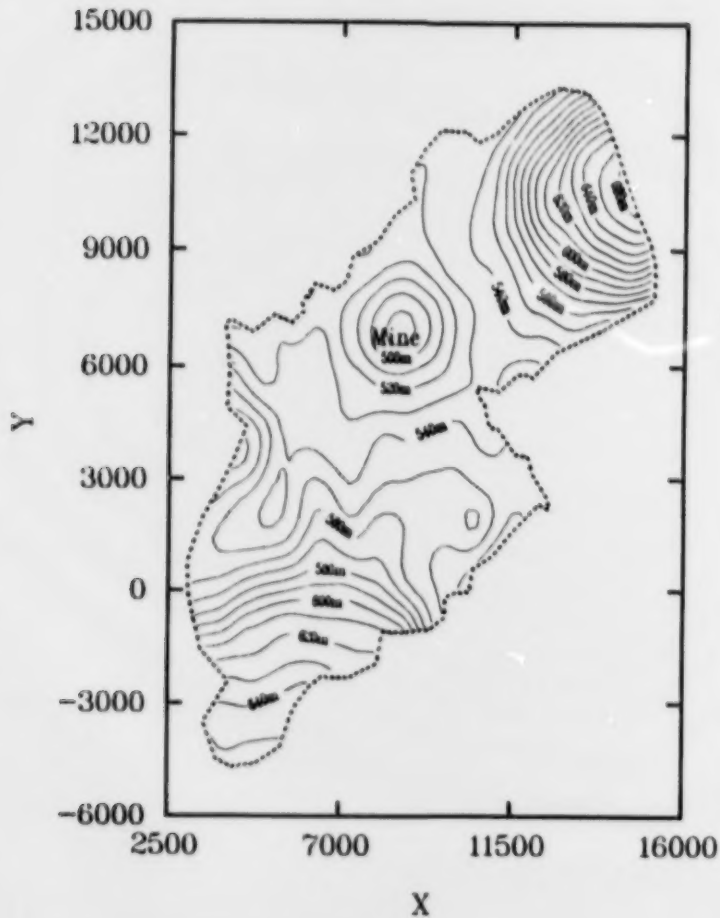


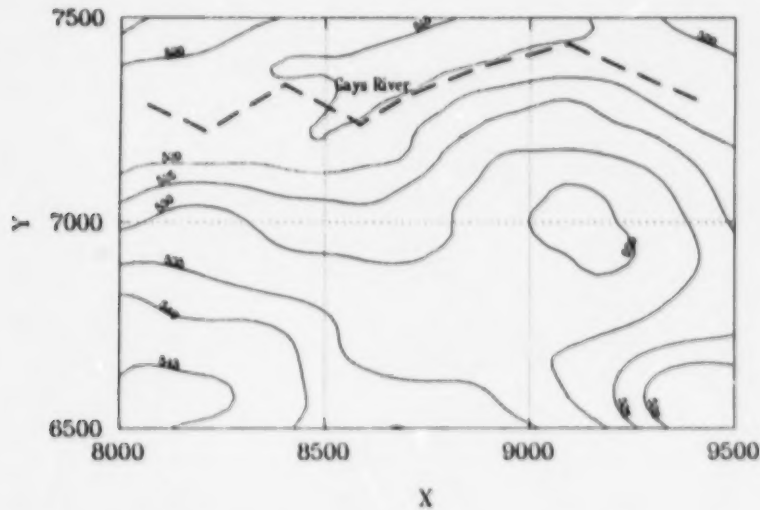
Figure 3-5

Configuration of the water table as modelled by the large-region model for mining conditions.

Gays River Regional Flow Model

Pre-Mine Case

Water Table



Gays River Regional Flow Model

Mine Case

Water Table

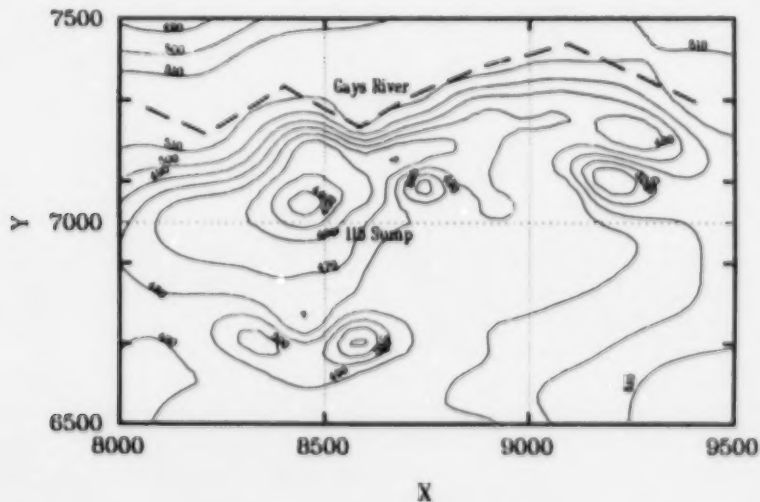


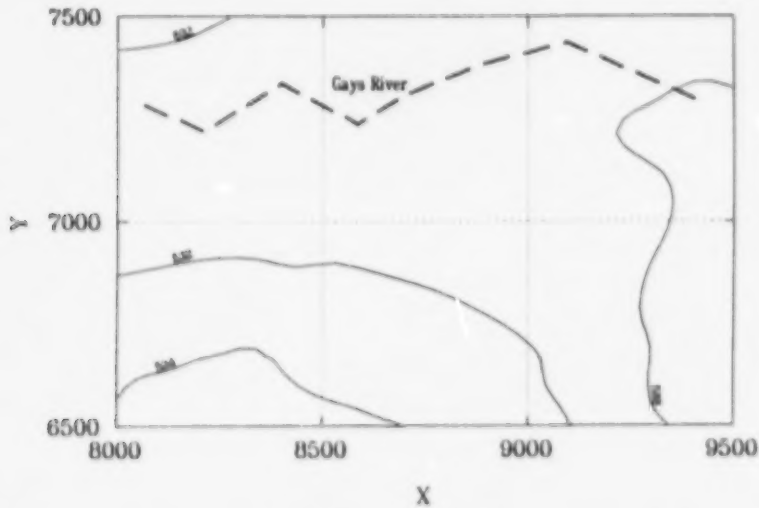
Figure 3-6

Comparison of the water table at the mine site for both pre-mining and mining conditions, as computed by the large-region model.

Gays River Regional Flow Model

Pre-Mine Case

Hydraulic Heads, 440 Level



Gays River Regional Flow Model

Mine Case

Hydraulic Heads, 440 Level

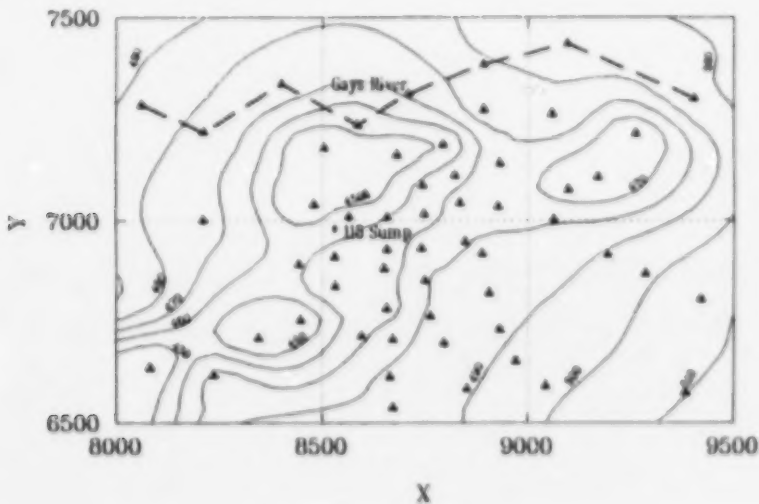


Figure 3-7

Comparison of hydraulic heads at the 440 level in the mine vicinity, for both pre-mining and mining conditions, as computed by the large-region model.

4.0 DETAILED MINE SIMULATION

4.1 Finite Element Mesh And Boundary Conditions

From the large-region model, an area surrounding the mine workings was identified to model groundwater flow in more detail. An area of approximately 16.8 km², bounded by local topographic highs and streams, defined the surface of the small-region model. A finite element mesh was constructed for this model that incorporated the detailed geology around the mine, including the major rock types such as the trench, river alluvium and overburden materials (Figure 4-1a). A greater number of nodes and elements were used in the small-region model, compared with the large-region model, to represent the mine area. This enabled the model to more closely simulate actual conditions around the mine area and identify local sources of mine inflow.

The small-region model was developed with the same approach used to construct the large-region model. The boundaries of the model were drawn along streams, rivers, lakes, and topographic divides wherever possible. Unlike the large-region model however, the small-region model had to simulate regional groundwater flow across its boundaries. This was achieved by extracting hydraulic heads from the large-region model and using them as input to the vertical boundary nodes of the small-region model. Heads at these nodes were held constant to reflect steady-state conditions. An impermeable or no-flow boundary was assigned to the base of the small-region model at the -500 m model level.

Ground and water table elevations for this model were extracted from the computer-gridded surfaces generated for the area. As in the large-region model, to enable the model to compute drawdown, the areal extent of the cone of depression was assumed and the nodes within the area were left free to vary. The surface area of the assumed cone of depression equalled the area specified in the large-region model (4.79 km²). All other surface nodes and nodes along streams and lakes were held at fixed head to simulate water table conditions. The mine excavations were simulated by assigning elevation heads to the nodes that outlined the mine workings in different model layers. A constant surface recharge of 1.308×10^{-9} m/s per m² was assigned to the surface elements within the cone of depression.

4.2 Model Input Parameters

The finite element mesh for the small-region model mesh was drawn to closely approximate the detailed mine geology. Particular attention was given to outlining the mine area and the trace of the trench. In this model the trench has been represented by a band of 5 metre wide elements. In addition, nodes were placed on or close

to sampling points being used by other sub-contractors in adjoining studies, to allow for future calibration of the model using the results of these studies.

The small-region model was subdivided vertically into ten layers (Figure 4-1b), using the same layering sequence as in the large-region model. The surface layer of the model was given a uniform thickness to represent overburden materials, consisting of clay till with local fluvial sands and gravels. The location and extent of the sand units were determined from plan maps and cross sections of recent shallow drilling by another sub-contractor, along with discussions with G. Meyer. The sand was assigned to model layer 1 for surface exposures (upper sand) and to model layer 2 if it was overlain by clay till (lower sand) (Figure 4-2). The main mining levels were represented by four 20 m thick layers (4 to 7) between the 480 m and 400 m mine levels, followed by three additional layers (8 to 10) with uniform thickness that penetrated to a depth of -500 m. Layers 2 and 3 had variable thicknesses which accounted for topographic effects in going from layer 1 to layer 4. All geological and layer interfaces were simplified by either horizontal or vertical contacts.

The distribution of element properties in the small-region model was based on the regional geology as well as several detailed cross-sections available for the mine area (Figure 4-3). Rocks of the Meguma Group formed the base of the flow model and in some areas were present in the upper layers. Evaporites in the model ranged from surface down to the 400 m mine level on the outside boundary and the carbonates, which were modelled mainly around the mine site, only extended to the 440 m mine level. Four cross-sections taken perpendicular to the trench were used to assign properties to each trench element, along with the adjacent elements to the north and south. Where necessary, the slope of the trench was approximated by assigning trench properties to adjoining elements in a step-like manner. Provision was also made to assign a line of high conductivity elements to the north side of the trench to simulate a high permeability zone along the trench-evaporite contact.

In the small-region model, the main rock types were assigned hydraulic conductivities obtained for the calibrated large-region model. The initial assignment of conductivity for the trench was 5.0×10^{-06} m/s, which is in the mid range of values calculated for trench material (Table 2-1). The sand units were assigned a K value of 1.0×10^{-04} m/s.

4.3 Model Calibration

The small-region model was used to evaluate groundwater inflow to the mine under two different flow conditions. Flow patterns around the mine were simulated for a low to average mine inflow of

approximately 4000 USgpm and a period of peak recharge and runoff. In the first simulation, the same hydraulic conductivities used in the final large-region model were assigned to the model elements and the high conductivity zone between the trench and the evaporites was not included. The total flux for the 86 nodes that simulated the mine was 5306 USgpm. This was higher than the 4197 USgpm calculated for the large-region model using the same input parameters. Two factors may have accounted for the difference in these results. First, the mine was represented by a greater number of nodes in the small-region model and this may have created a larger effective zone of influence by the mine. Second, the fluvial sands and gravels along with the trench sediments have been included in this model. The relative difference in material conductivities, such as between the highly conductive upper sands and the low permeability clay till, would have altered the distribution of flow to allow more water to recharge the system.

To calibrate the model against total flux, the conductivities were proportionally reduced (Table 4-1) to achieve a mine inflow of approximately 4000 USgpm. In addition, a 1 m wide, high conductivity zone was introduced at the contact between the trench and evaporites. A conductivity of 2.5×10^{-05} m/s was assigned to the appropriate elements. This value was calculated from an equivalent transmissivity since the representative elements in the model had an average width of 40 m. These alterations to the model resulted in a total mine flux of 4017 USgpm. This was a good approximation of groundwater inflow to the mine for low to average recharge conditions.

Table 4.1 Hydraulic conductivities assigned to geological materials of the small-region model.

MATERIAL	K_h (m/s)	K_v (m/s)
Overburden	7.2×10^{-08}	7.2×10^{-09}
Sand	7.2×10^{-04}	3.6×10^{-04}
Trench	3.6×10^{-06}	1.8×10^{-06}
Evaporites	2.4×10^{-06}	1.2×10^{-06}
Carbonates	1.2×10^{-06}	6.0×10^{-07}
Quartzites	3.6×10^{-08}	1.8×10^{-08}
High K Zone	3.0×10^{-05}	1.5×10^{-05}

Mine inflows were then simulated for high recharge conditions. The surface recharge was doubled to 2.616×10^{-9} m/s per m^2 and the nodes adjacent to Gays River were assigned fixed heads to simulate the saturated flood plain. The total mine flux for this simulation

was 4098 USgpm, which was an increase of only 81 USgpm over the previous simulation. Since very little data was available on the hydraulic conductivity of the river alluvium it was assigned a value equal to the conductivity of the clay till. A higher conductivity for the alluvium would probably have increased flow to the mine.

4.4 Model Results

Hydraulic head data obtained from the low to average flow simulation are contoured in Figures 4-4, 4-5 and 4-6. Large scale contour maps for these levels are also provided in Appendix B. The water table configuration for this model (Figure 4-4) shows a maximum drawdown to the 480 m mine level, centred over the 118 sump. This model indicates that there is less drawdown around the mine area than shown in the large-regional model, which is probably more realistic of actual conditions since the rock mass above the mine is partially to fully saturated (i.e. perched water table). This model has also included higher permeability sand units that are able to conduct more water from surface, decreasing the amount of drawdown around the mine.

The specific effect of differentiating the overburden and including the sand units can be seen in the central area of the map, north of Gays River. Hydraulic gradients in areas underlain by sand (see Figure 4-2) are relatively low and become significantly steeper in areas where the clay till is present.

Figures 4-5 and 4-6 present the hydraulic heads at the 480 m and 440 m mine levels, respectively, and show that the zone of influence of the mine is significant at depth. These plots also show that the cone of depression is slightly elongated, following the outline of the trench and the mine workings. These contour plots indicate that water is being pulled into the mine from regional as well as local sources.

Figure 4-7 shows the water table for the case of the simulated flood plain. The effect of a saturated versus unsaturated flood plain on the distribution of head at surface is shown in Figure 4-8. For a saturated flood plain, a broad flat area is present to the north of the simulated mine, above the 515 m contour, which is much greater in area than the simulation without the flood plain. While the larger size of the flood plain has also increased the gradients toward the mine, there is only a 81 USgpm increase in flux to the mine compared with the low to average flow simulation. This increase in total mine flux probably remained small because the model did not account for the presence of discrete sinkholes in Gays River and possibly because the permeability data provided for the flood plain materials were too low. Therefore, these results suggest that (1) regional groundwater flow is an important component of the baseflow of approximately 4000 USgpm to the mine;

and (2) that sinkholes in Gays River and(or) the flood plain are probably responsible for channelling surface water to the mine during periods of high flow.

4.5 Pathway Predictions

CFEST was used to calculate groundwater flow pathways for the small-region model. The primary objective of this exercise was to identify the source(s) of inflow to the mine as an aid to the design and siting of control and(or) remediation measures.

Eleven pathlines were computed for the small-region model. Pathlines were computed for points in the mine with large inflows, including the 118 sump area and the 808 cross-cut area, as well as from possible sources of surface water such as Mosher's Quarry and Gays River. Plan views of the eleven pathlines and section views of the longest of these pathlines are shown in Figure 4-9.

Pathlines (Figure 4-9) varied greatly in direction and length, ranging from straight lines of only a few metres in length to curved lines that were kilometres long. Pathlines 1 to 5 were used to examine the sources and paths of groundwater to the simulated mine. Pathline 1 suggests that groundwater discharging in the 808 cross-cut area (426 m mine level) is derived from a source located about 2 km to the west. In this case, the pathline originated in overburden, migrated to a depth of 30 to 40 m in the evaporites before it returned to the base of the overburden, directly below Gays River. This is an indication that groundwater is discharging into Gays River at that point. The flattening and continuation of the pathline toward the mine may be a result of numerical uncertainty at the element boundaries between overburden and bedrock. After travelling horizontally for a distance of 500 m, the pathline turned sharply downwards, implying recharge to the high permeability evaporites at this location. The pathline then showed that groundwater was drawn into the simulated mine, passing beneath the low permeability trench sediments before it discharged at the 808 cross-cut.

Pathline 2 (Figure 4-9) suggests that groundwater, or at least a component of groundwater discharging into the 118 sump (405 m mine level), was recharged from a source north of the mine. According to this pathline, groundwater travelled through Meguma Group rocks to a depth of 400 m below the sump before turning upwards and discharging into the mine. This pathline was terminated by the model, near its northern boundary, before the point of recharge could be identified. This suggests that the recharge area was probably north of the small-region model boundary. Pathline 2 shows that regional groundwater flow probably does contribute to the total inflow at the 118 sump, but it does not imply that all inflow to the 118 sump is derived from a distant recharge source.

It is expected that shallow and local sources of groundwater are also important components of the total inflow to the 118 sump.

Pathline 3 (Figure 4-9) suggests that groundwater discharging in the 826 ramp (442 m mine level) was recharged west of the model boundary. From there, groundwater was channelled through evaporites to below the 200 m level of the model. Then the pathline turned upwards to reach the 400 m mine level before being drawn laterally into the mine.

Pathlines 4 and 5 (Figure 4-9) start at the 211 drift (453 m mine level) and the 212 drift (482 m mine level), respectively. Both of these pathways are relatively short and near-vertical, signifying local and shallow recharge sources for inflows to these areas of the mine.

Another six pathlines were started from points at or near surface to test the significance of Mosher's Quarry (pathline 6), Gays River (pathlines 7, 8, 9, and 10) and the tailings pond (pathline 11) as sources of inflow to the mine. The resulting pathlines were short and none of them were drawn into the simulated mine, demonstrating that these are not sources of inflow to the mine as it has been modelled. This is acceptable in terms of Mosher's Quarry and the Tailings/polishing pond, but the pathlines are contrary to field evidence that suggest Gays River is a source of inflow to the mine at certain locations. This suggests that instead of representing the sinkholes as an average condition, as was done in this preliminary modelling, the model should be adjusted to reflect the discrete nature of the sinkholes.

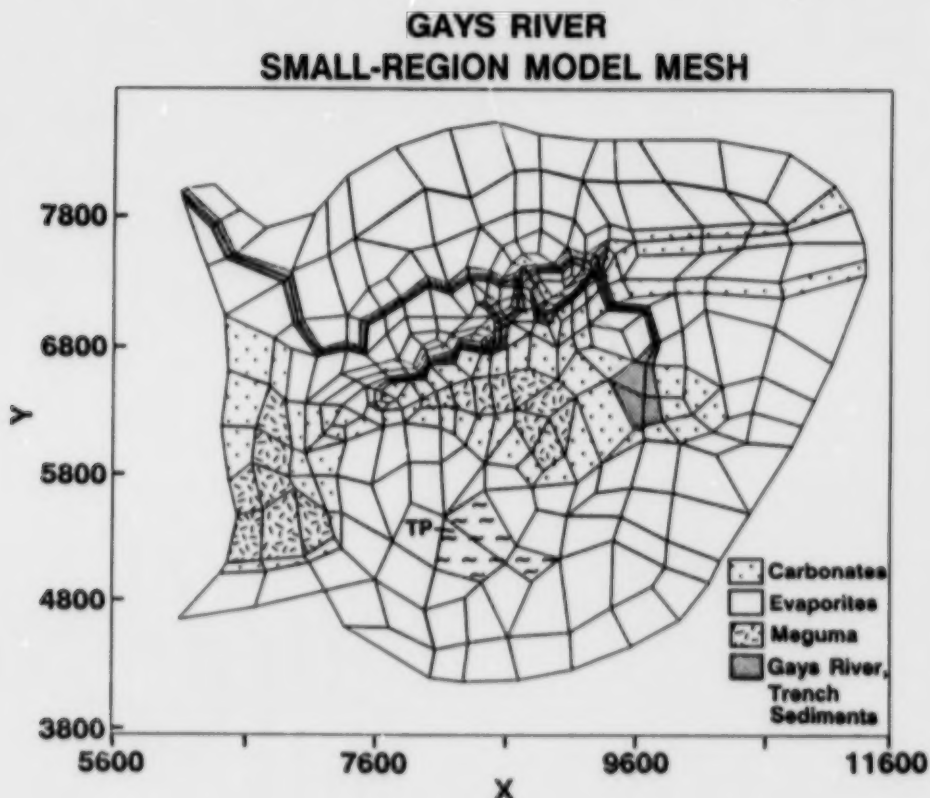


Figure 4-1

(a) Finite element mesh for the small-large region, groundwater flow model (above) and (b) associated well logs that describe the layering sequences (next).

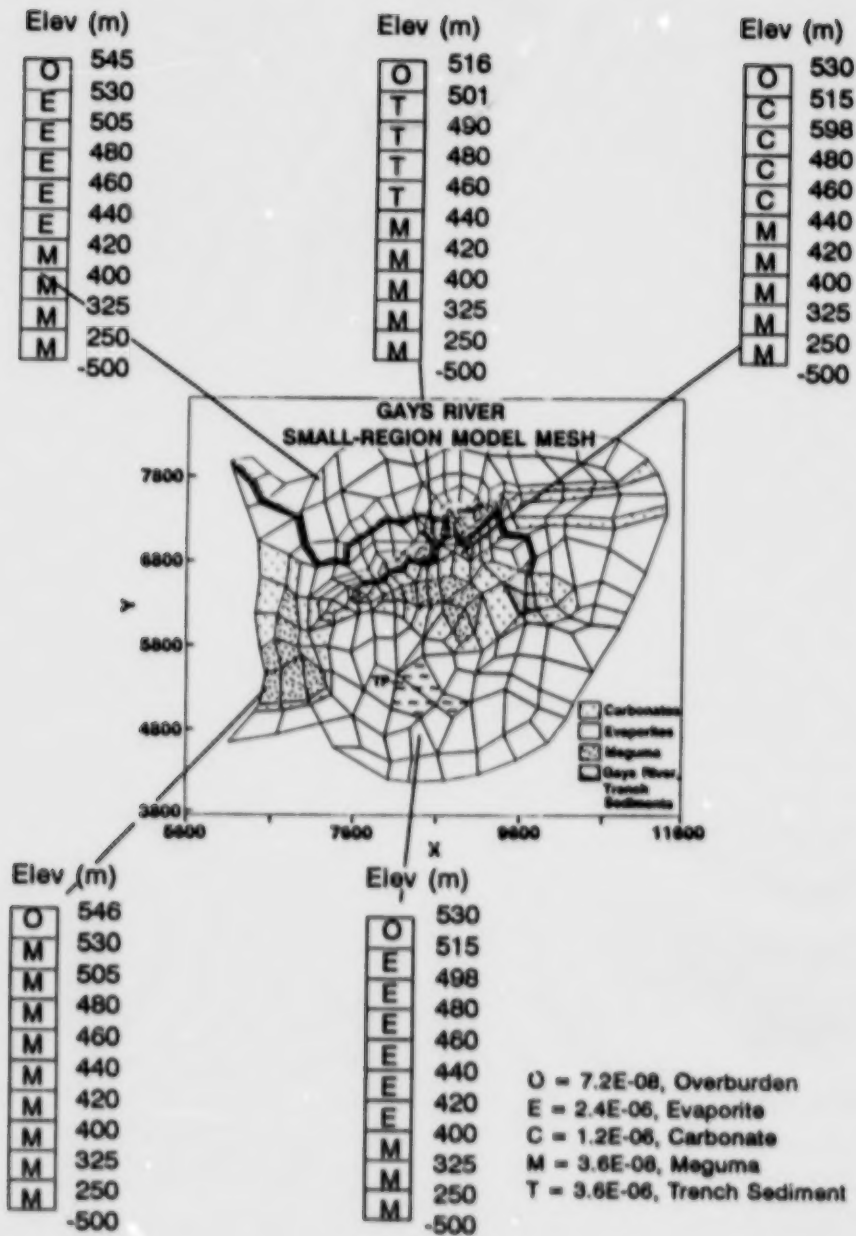


Figure 4-1 Continued.

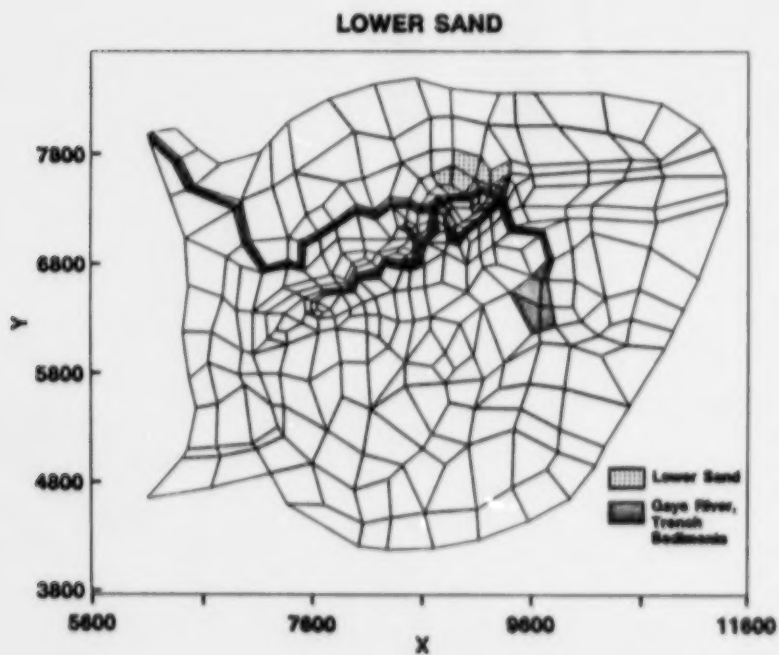
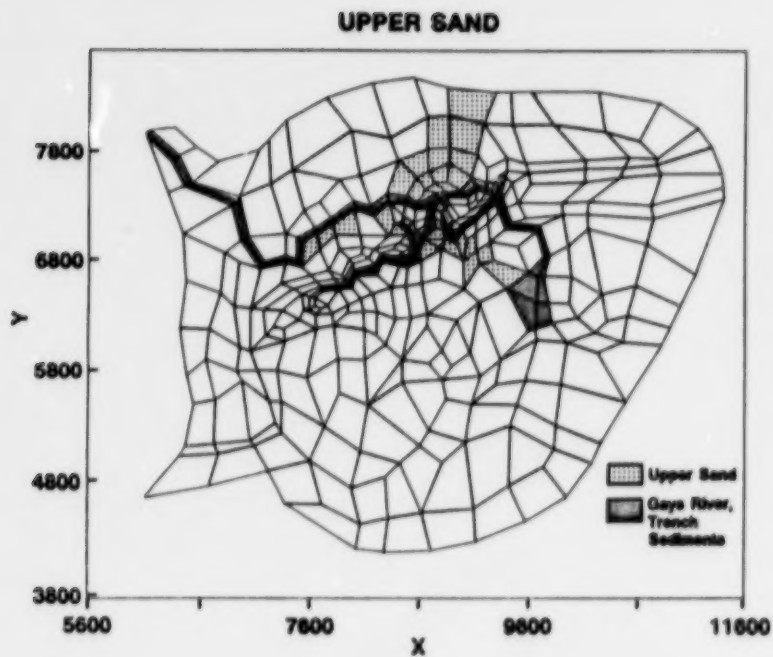


Figure 4-2 Location of sand units.

Gays River Small-Region Flow Model

Cross-Section Locations

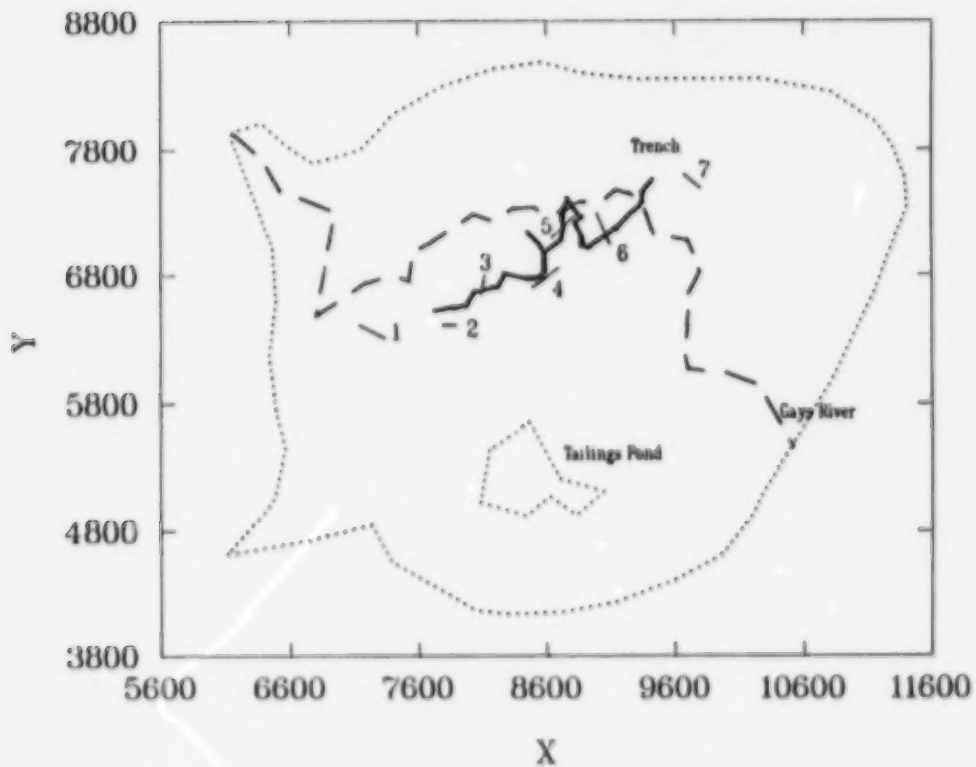


Figure 4-3 Location of cross-sections used to determine material property assignments for the small-region model.

Gays River Small-Region Flow Model

Water Table

No Simulated Floodplain

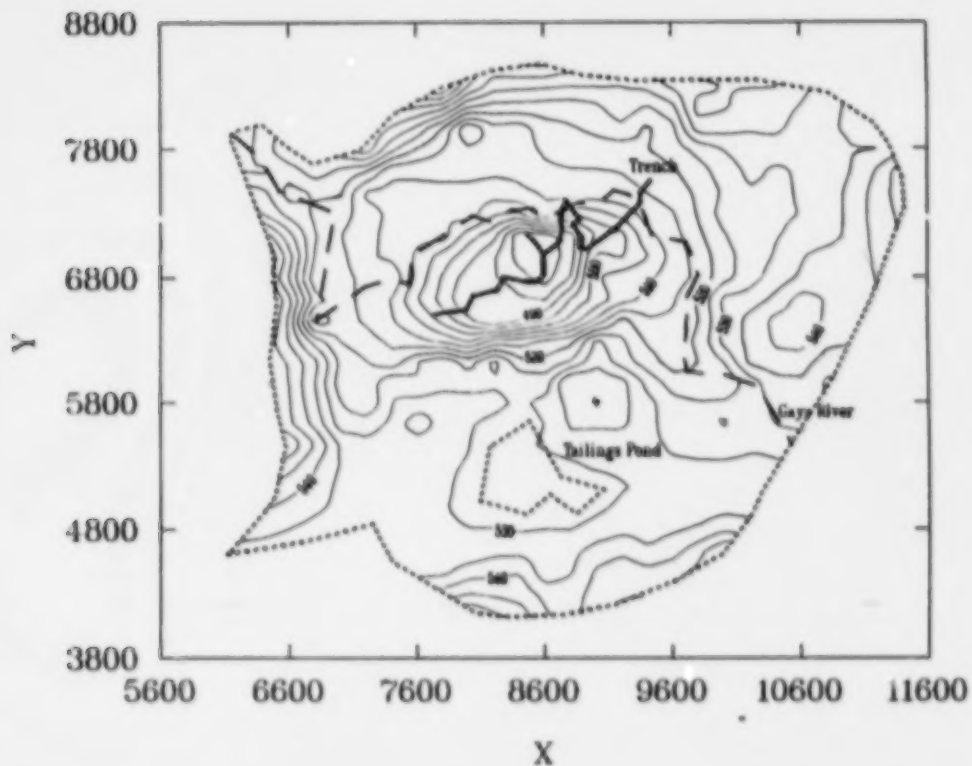


Figure 4-4

Configuration of the water table as modelled by the small-region model without the simulated flood plain.

Gays River Small-Region Flow Model

Hydraulic Heads, 480 Level

No Simulated Floodplain

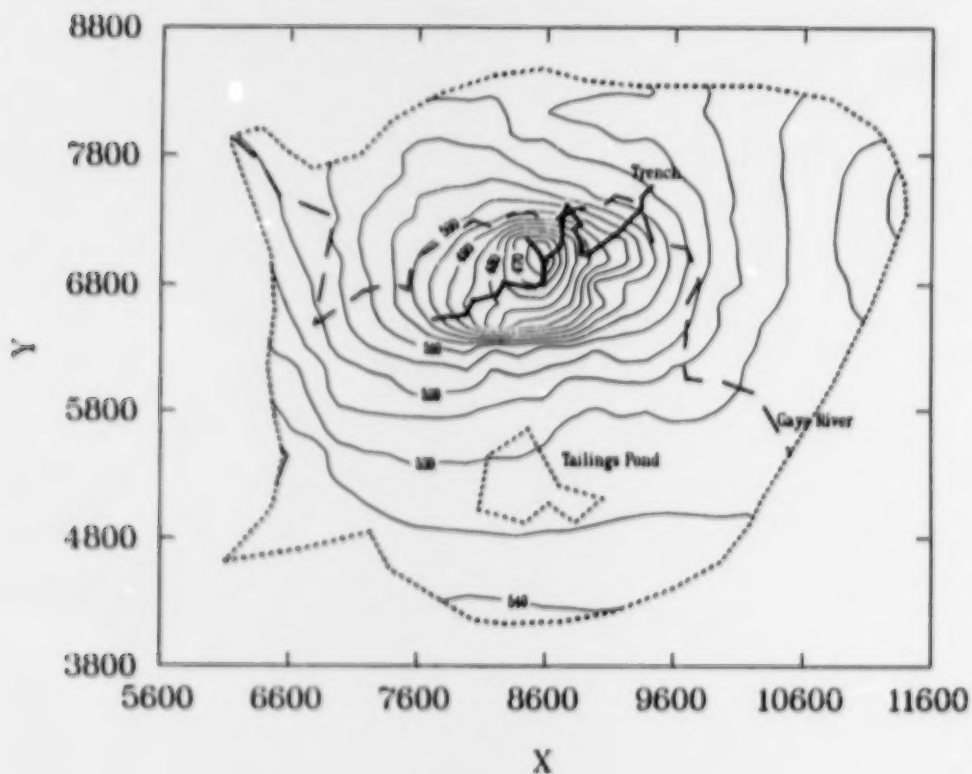


Figure 4-5

Hydraulic head distribution at the 480 m level as computed by the small region model without the simulated floodplain.

Gays River Small-Region Flow Model

Hydraulic Heads, 440 level

No Simulated Floodplain

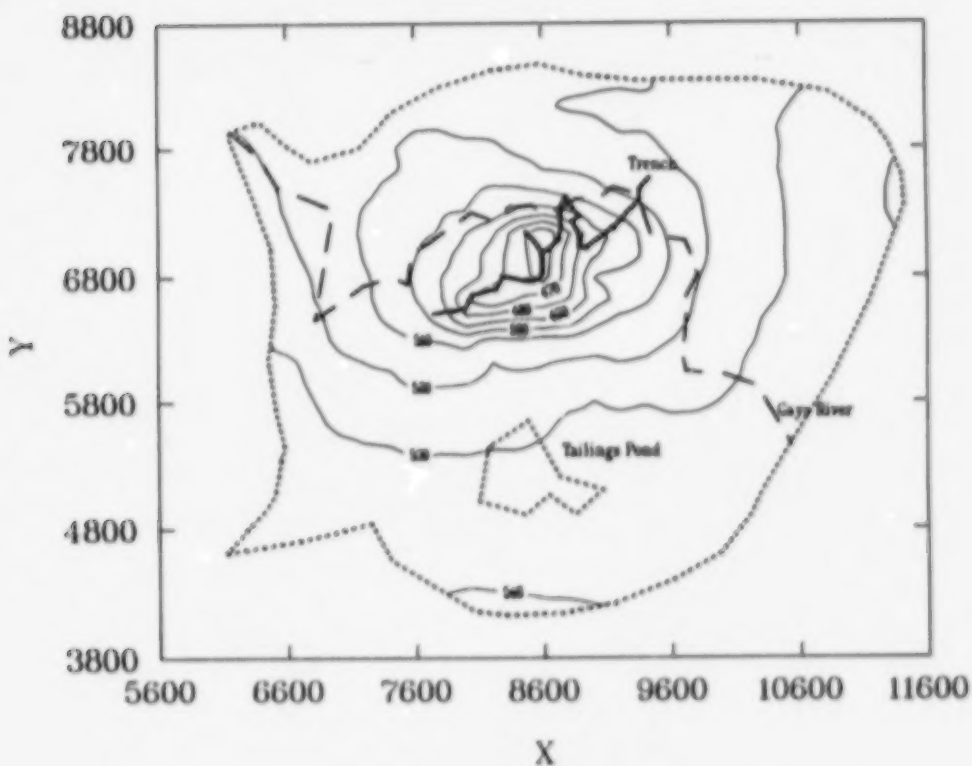


Figure 4-6

Hydraulic head distribution at the 440 m level as computed by the small-region model without the simulated flood plain.

Gays River Small-Region Flow Model

Water Table

Simulated Floodplain

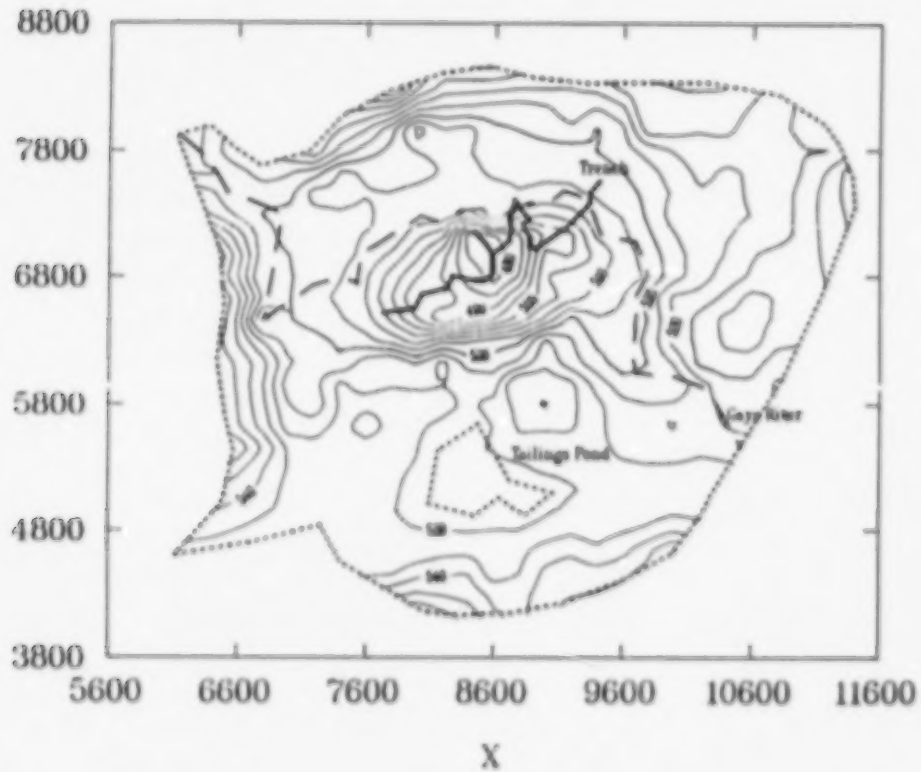


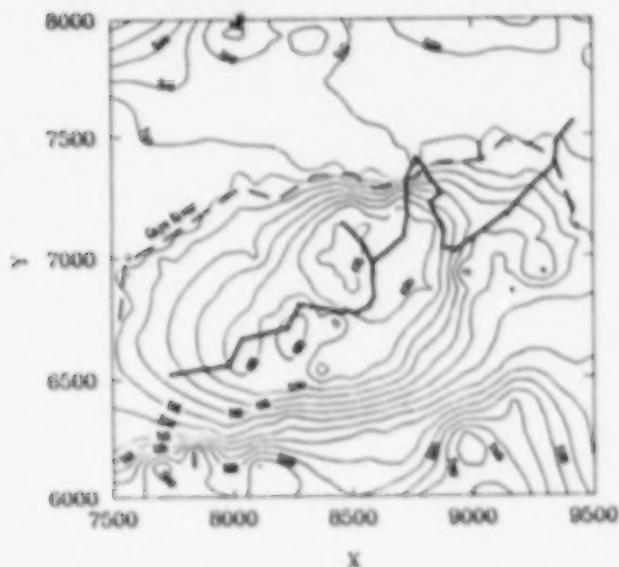
Figure 4-7

Configuration of the water table as modelled by the small-region model with the simulated flood plain.

Gays River Small-Region Flow Model

Base Map

No Simulated Floodplain



Gays River Small-Region Flow Model

Base Map

Simulated Floodplain

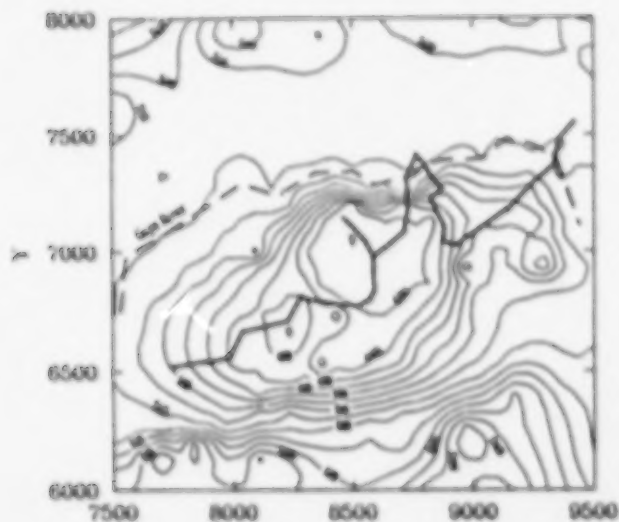


Figure 4-8

Comparison of water table at the mine site as computed by the small-region model with and without the simulated flood plain: note that the contouring function provides more detail, compared with previous figures.

Pathway Predictions Gays River Small-Region Flow Model

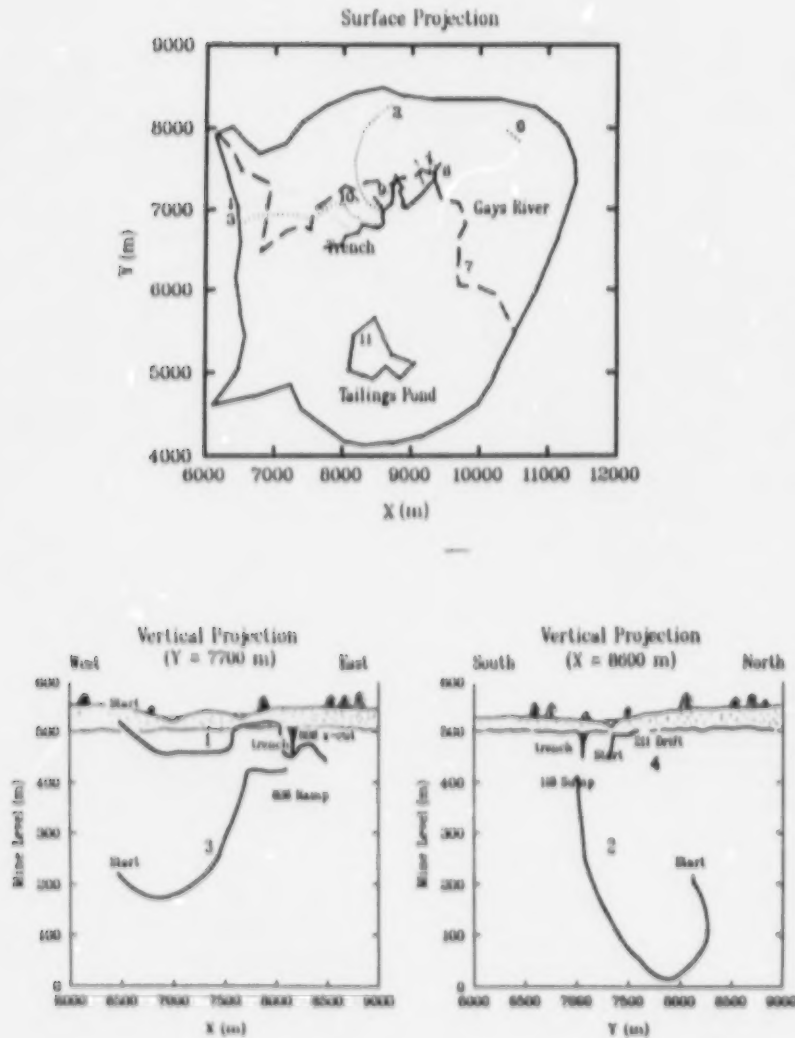


Figure 4-9

Plan view of 11 pathlines computed for the small-region model (top) and cross-section views of pathlines 1 to 4: surface topography and overburden thickness are conceptualized.

5.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

For more than 10 years, hydrogeological investigations have been conducted at the Gays River mine site in an attempt to identify and control groundwater inflows. These previous investigations however, conducted by different mine operators and different consulting groups, lacked a common strategy and scope. This has made it difficult to interpret the data base and develop an understanding of the groundwater flow system at this site. Recently, Westminer Canada and CANMET organized a structured and multi-disciplinary investigation and Fracflow Consultants was assigned the task of constructing a baseline groundwater flow model of the site using available data.

A finite element computer code, CPEST, was used to model the regional and local groundwater flow systems surrounding the Gays River mine. A nested model approach was used here, whereby a large-region model was constructed and executed before modelling groundwater flow at the mine site in detail. This approach enabled the regional controls on hydraulic heads to be reflected in the detailed, small-region model. The large-region model (111 km²), which accounted for the mine excavations, general geology, and main hydrogeological features in the drainage basin, was developed and used to simulate a low-to-average mine dewatering rate of 4197 USgpm. The computed heads and gradients were found to be comparable to general site conditions and it therefore provided reasonable external head conditions for the boundaries of the small-region model.

The small-region model (16.8 km²) incorporated the detailed hydrogeological features around the mine site and simulated both low-to-average and high (i.e. saturated flood plain, high infiltration) flow periods of the year. The total mine flux in the low-to-average flow simulation was 4017 USgpm and the distribution of hydraulic heads around the mine workings were in reasonable agreement with measured heads around the mine site. High flow conditions were then simulated by including a saturated flood plain in the model and by doubling surface infiltration (2.616×10^{-9} m/s per m²). This increased the total mine flux by only 81 USgpm, although an obvious effect on the distribution of heads and gradients was observed at the model surface. This small increase in mine flux under wet conditions suggests that at the mine site:

- Regional groundwater flow is probably an important component of the baseflow of approximately 4000 USgpm to the mine;
- Sinkholes in Gays River and(or) the floodplain are probably responsible for channelling surface water to the mine during periods of high flow; and that

- Surface recharge through the overburden may be greater than average.

The difference in mine flux between low-to-average and high flow simulations would probably have been greater if (1) sinkholes are modelled as discrete features along the bottom of Gays River; and (2) if higher permeabilities for the river bottom and floodplain sediments are assumed in the model.

Pathlines of groundwater flow were computed by the small-region model to help identify specific sources of groundwater inflows to the mine. Eleven pathlines were generated for the small-region model for starting points in the mine and at surface. Pathlines were found to vary greatly in direction and length, ranging from straight lines of only a few metres to curved lines that were kilometres long. One flow path was traced to the 808 cross-cut (426 m mine level) from an overburden source located about 2 km to the west. Another flow path was defined for the 118 sump (405 m mine level), which appeared to be recharged several kilometres to the north, beyond the boundary of the small-region model. Other pathlines that were started from points along Gays River, Mosher's Quarry and the tailings pond were short in length and did not reach the mine. In general, the pathlines suggest that inflows to the deeper levels of the Gays River mine include a component of regional groundwater flow, while upper levels in the mine receive influx from near-surface sources.

The model described in this report was developed to reflect the available data and our present understanding of mine conditions. As a baseline model, it can be modified to test different mine inflow conditions and test the effects of possible remediation measures. Improvements to the flow model and a better understanding of the hydrogeology of the mine site can be achieved in the followings ways:

1. Modify the existing flow model to reflect the additional data that has been collected on the distribution of overburden materials, solution cavities;
2. Model sinkholes in Gays River and its flood plain as discrete features, to determine their effect on total mine flux for low-to-average and high conditions. This can be achieved by linking a series of high conductivity model elements between Gays river and the mine, using the travel times from earlier dye experiments to determine the overall geometry of the pathways between the sinkholes and the mine;
3. Reinterpret the estimates of both the recharge rates in the mine area and the hydraulic conductivities of the flood plain materials, based on the more recent field work;

4. Groundwater flow paths calculated by the model provide an effective means of comparing the hydraulic data with the chemical and isotopic data collected by other sub-contractors. This work should be done in order to constrain the interpretation of the groundwater sources and pathways;
5. Storage coefficient data for the different geological materials should be used in the model to run transient simulations, which would provide a better picture of the sources of water in the short-term;
6. With the above modifications to the flow model, locate zones of significant groundwater inflows into the simulated mine for the purpose of targeting underground drainholes and(or) surface "drainwells";
7. Test the effect of potential groundwater control and remediation measures, such as drainholes, "drainwells", and grout curtains, on reducing mine inflows.

6.0 ACKNOWLEDGEMENTS

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APPENDIX A

HYDROLOGIC DATA CALCULATIONS

A.1 Introduction

Several different data sets were used to estimate the hydraulic conductivity (K) of the various geological materials around the Gays River mine site (see Table 2-1). These include grain-size analyses, water-level recovery tests in observation wells, and pump tests as discussed in Chapter 2. The formulation that was used to relate soil texture to hydraulic conductivity is simplistic (Hazen's power law; see Chapter 2) and, therefore, detailed data calculations are not given here for the analyses of grain-size data. Analyzing the pump test and water-level recovery data was not always straight-forward, however, because of the limited and often incomplete nature of the information available. Consequently, the following section is used to clarify the methods and specific data used to estimate K values from pumping and recovery data.

A.2 Pumping And Recovery Tests

Constant-rate pumping tests conducted in geological formations can provide some of the most reliable information for T and S determinations. The Jacob straight-line method (Driscoll, 1987; Fetter, 1988) was used here to analyze the results of such pumping tests. The log time versus drawdown data were plotted, a straight line was drawn through the data points, and the line extended backwards to the zero drawdown axis; the intercept designated t_0 . The drawdown per log cycle (Δs) was then measured along the slope of the line. The value of T was obtained using the following equation:

$$T = \frac{0.183 \cdot Q}{\Delta s}$$

Transmissivity is a measure of the quantity of water (e.g. m^2/day) that can move through the saturated thickness of the aquifer (b) under a hydraulic gradient of 1;

$$T = K \cdot b$$

Observation well data was analyzed similarly, when available, but the coefficient of storage could also be calculated from this data using the following expression:

$$S = \frac{2.25 \cdot T \cdot t_0}{r^2}$$

where, r is the distance from the pumped well to the observation well. The Jacob straight-line method can also be used with the recovery data collected after the pump test is complete. Some pump

A-3

test and recovery data were available to evaluate the transmissive properties of the Windsor Group evaporites and carbonates. A 15 day pump test was conducted by Dames and Moore (1980) at the mine site. DW-3 was selected as the pumping well, which was supposedly pumped at a rate of between 500 to 700 USgpm (Meyer, 1990). Figure A-1 shows both a semi-log and a log-log plot of the time-drawdown data for this pumping well.

Observation wells H-2, H-3, H-4, OW-1A, and OW-1 were monitored during the test, but only data for wells H-4 and OW-1A responded consistently and showed significant drawdowns (Figures A-2 and A-3). Meyer (1990) analyzed the early part of the time-drawdown curves calculated transmissivities of 370-520 m²/day between DW-3 and OW-1a (N-S direction), and 600-840 m²/day between DW-3 and H-4 (E-W direction).

Dames and Moore's (1980) late time-drawdown data for H-4 (Figure A-2) and OW-1A (Figure A-3) were analyzed here because of the constant slope for each data set over longer periods of time. This was believed to be more representative of flow through larger volumes of rock and, consequently, this analysis was expected to provide a better average transmissivity for input to the numerical model. In support of this contention, the log-log plot of time-drawdown data for DW-3 (Figure A-1) shows an approximate straight-line relation, which reflects a strong component of linear flow (i.e. channelled flow through a high permeability zone) rather than a dominant radial flow component. This means that the transmissivity calculated using the early-time data could be strongly biased toward local flow conditions along the high permeability zone, while later-time data probably reflect a steady contribution of water from the surrounding rock mass. Key information and results of these calculations are shown in Table A-1. Note that *b* was estimated using the well logs presented in Jacques, Whitford and Associates (1990) and Tables 1 and 2 in Meyer (1990).

Table A-1 Data used and results from the analysis of pump test data collected by Dames and Moore (1980). *Q* is assumed to be equal to 600 USgpm (or 2.3 m³/min) based on the estimated range of *Q* reported in Meyer (1990).

WELL	<i>b</i> (m)	<i>t_s</i> (days)	Δs (m)	<i>r</i> (m)	<i>T</i> (m ² /day)	<i>S</i>	<i>K</i> (m/s)
OW-1A	6	7.2E-04	1.5	445	400	2.0E-04	7.7E-04
H-4	26	4.9E-03	1.7	554	352	7.6E-04	1.6E-04

A-4

Using an average Q of 600 USgpm, T is found to be 400 m^2/day between OW-1A and DW-3, and 352 m^2/day between H-4 and DW-3. Because of the uncertainties involved in the analyses however, it is assumed that the bedrock has a constant transmissivity in the horizontal plane.

The conductivities of the evaporites and carbonates were assessed further by analyzing the water-level recovery data during the mine close-out period, from August 12 to October 27, 1982 (Leggette, Brashears & Graham, 1983). An analogy is made between conducting a short-term, constant-rate pump test in a well and conducting a long-term, constant-rate pump test by dewatering mined excavations. Assuming an average mine discharge of 4000 USgpm, log time is plotted against recovery data for the ETW, OW, and DW series of holes, as well as for H-4 (Figures A-4 to A-6). Key information and results of these calculations are shown in Table A-2.

Table A-2 Data used and results from the analysis of pump test data for the mine close-out period, 1982 (Leggette, Brashears & Graham, 1983). Q is assumed to be equal to 4000 USgpm (or 15.1 m^3/min).

WELL	b (m)	t_o (days)	A_s (m)	r (m)	T (m^2/day)	S	K (m/s)
DW-1	56	24.8	46.1	300	86	5.3E-02	1.8E-05
DW-2	5.5	7.0	21.3	440	187	1.5E-02	3.9E-04
DW-3	60	1.1	34.0	140	117	1.5E-02	2.2E-05
H-4	26	17.0	36.1	550	110	1.4E-02	4.9E-05
ETW-1	33	1.3	32.6	180	122	1.1E-02	4.3E-05
ETW-2	45	3.0	30.5	380	131	6.0E-03	3.4E-05
ETW-3	---	6.7	25.9	920	154	2.7E-03	---
OW-1A	6	5.6	35.8	180	111	4.3E-02	2.1E-04
OW-2	6	12.0	53.1	460	75	9.6E-03	1.4E-04
OW-3	3	26.2	37.6	980	106	6.5E-03	4.1E-04

-- No well log available

A.3 Water-Level Recovery Tests

During a recovery test, the static water level is initially recorded, a volume of standing water is removed from the well, and the water-level is then monitored with time during its return to the static head condition. Such recovery tests were performed on groundwater monitoring wells DW-1, DW-2, OW-3, and ETW-4 (Lamb, 1990).

The water-level recovery data were analyzed using the method of Hvorslev (1951; see also Fetter, 1988). Time was plotted against the log of the drawdown to determine the slope (H_1/H_2) of the recovery curve, and the following equation was used to compute K:

$$K = \frac{d^2 \cdot \ln \left[(2 \cdot m \cdot L) / D \right]}{8 \cdot L \cdot (t_2 - t_1)} \cdot \ln \frac{H_1}{H_2}$$

where, D = diameter at the well screen,
 d = diameter of the standpipe,
 L = length of the screen,
 H_1 = head at time t_1 ,
 H_2 = head at time t_2 ,
 m = ratio of horizontal to vertical conductivity (assumed to be 1 here).

Table A-3 Data used and results from the analysis of water-level recovery tests: LT = late time part of the graph, ET = early time part of the graph, AT = average of an early and late time analysis.

WELL	D (m)	d (m)	L (m)	H_1/H_2 (m)	K (m/s)
DW-1	0.254	0.254	15.2	4.6 AT	9.9E-08
DW-2	0.391	0.391	5.5*	1.6 ET	3.0E-06
OW-3	0.152	0.152	15	2.7 LT	5.6E-08
ETW-4	0.203	0.203	---**	---	---

* Interval defined by base of clay till (29 m) to the bottom of the open hole (34.5 m; T. Lamb, Fers. Comm.)

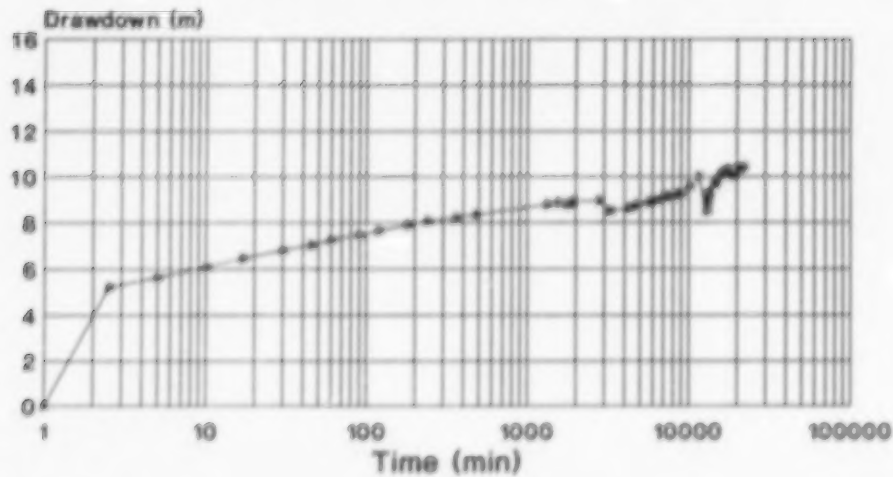
** No well log available

A-6

Time-drawdown data are plotted for DW-1, DW-2, OW-3, and EFW-4 in Figure A-7. This type of analysis can yield estimates of K that are reasonable and accurate to within an order of magnitude depending, of course, on the quality of data used. Well logs presented in Jacques, Whitford and Associates (1990) were used to determine L: where L is not specified or where the hole is open over its entire bore, L was estimated by assuming the length of the major inflow zones. Key information and results of these calculations are shown in Table A-3.

A-7

DW-3
Pump Test
Dames and Moore, 1980



DW-3
Pump Test
Dames and Moore, 1980

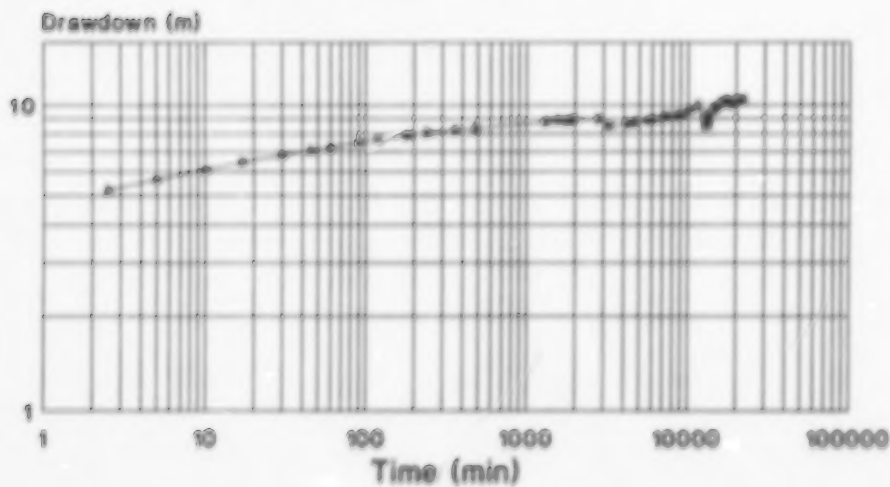
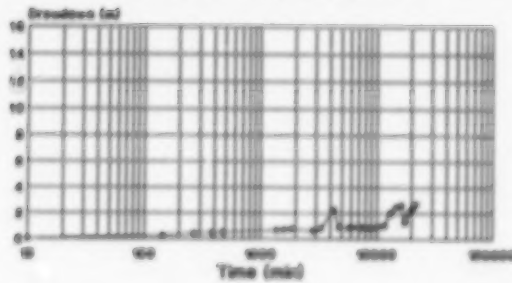
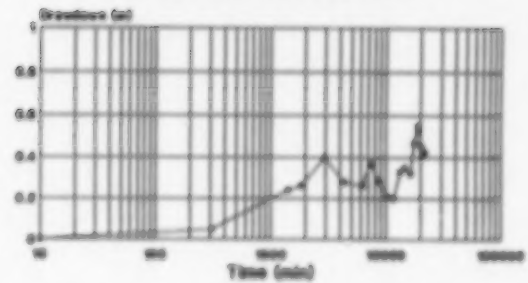


Figure A-1 Pump test data for DW-3 (Dames and Moore, 1980) plotted on semi-log and log-log graphs.

H-2
Pump Test
Dames and Moore, 1980



H-3
Pump Test
Dames and Moore, 1980



H-4
Pump Test
Dames and Moore, 1980

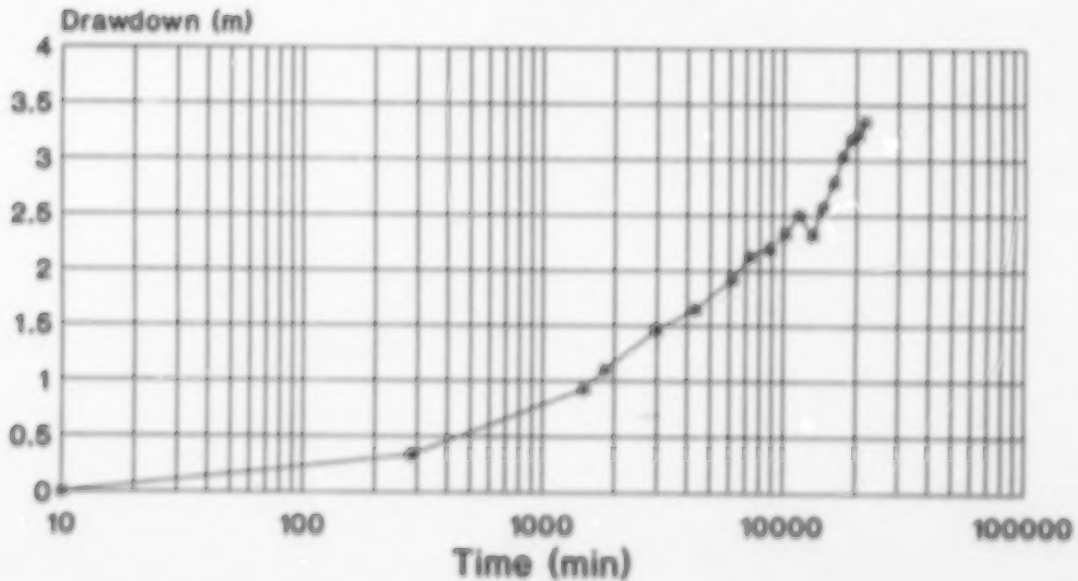
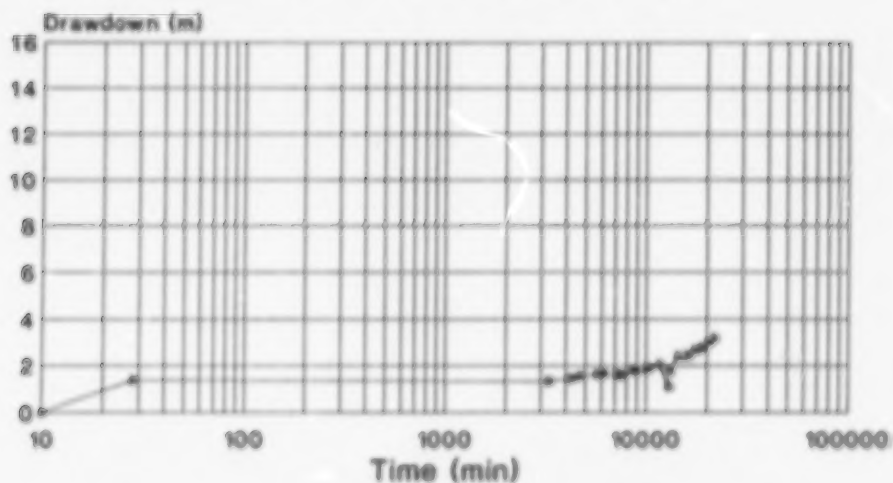


Figure A-2

Observation well data collected for H-2, H-3, and H-4 during the DW-3 pump test (Dames and Moore, 1980), plotted on semi-log diagrams.

A-9

OW-1
Pump Test
Dames and Moore, 1980



OW-1A
Pump Test
Dames and Moore, 1980

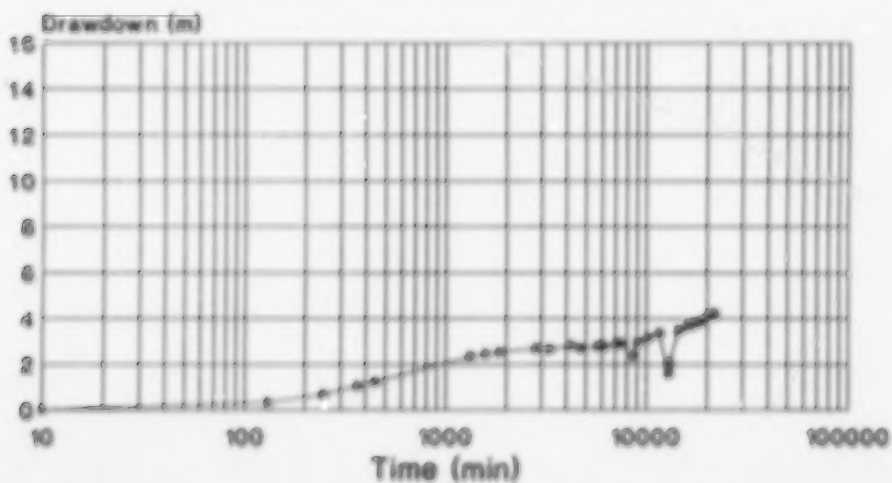
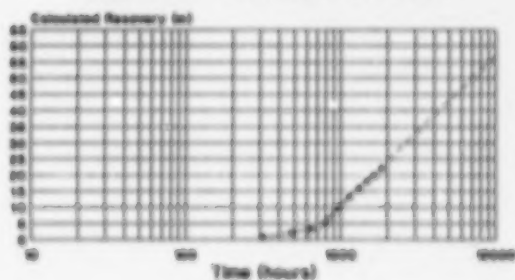
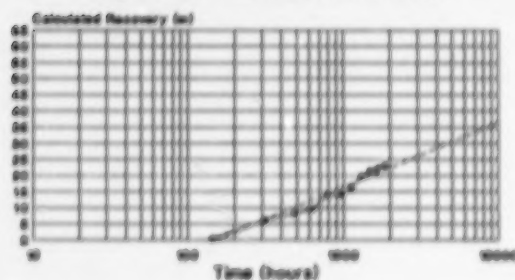


Figure A-3 Observation well data collected for OW-1 and OW-1A during the DW-3 pump test (Dames and Moore, 1980), plotted on semi-log diagrams.

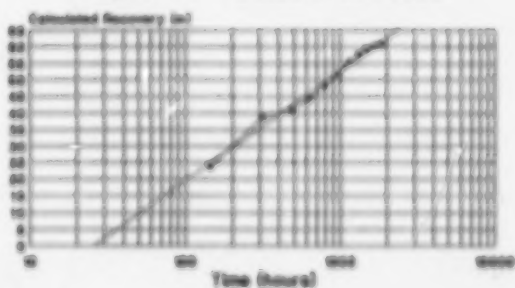
DW-1
Recovery Data
August 12 - October 27, 1982



DW-2
Recovery Data
August 12 - October 27, 1982



DW-3
Recovery Data
August 12 - October 27, 1982



H-4
Recovery Data
August 12 - October 27, 1982

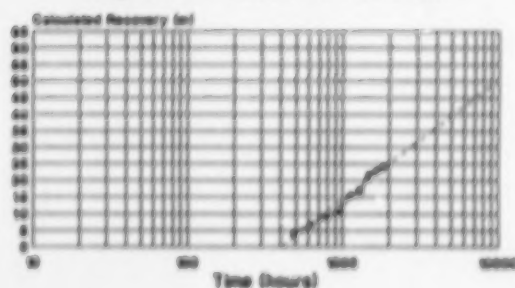


Figure A-4

Recovery data collected for wells DW-1, DW-2, DW-3 and H-4 during the mine close-out period in 1982 (Leggette, Brashears & Graham, 1983), plotted on semi-log diagrams.

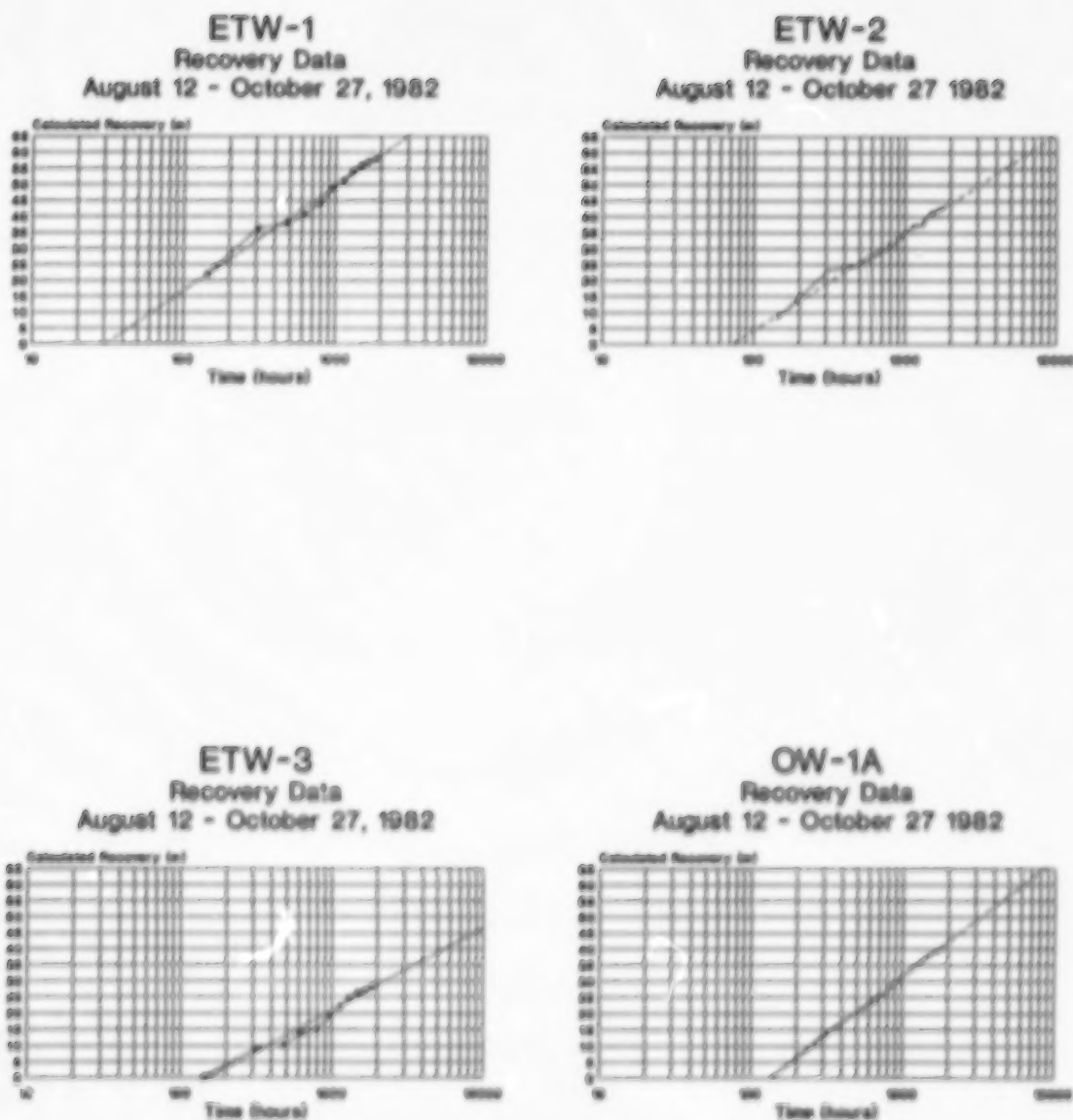
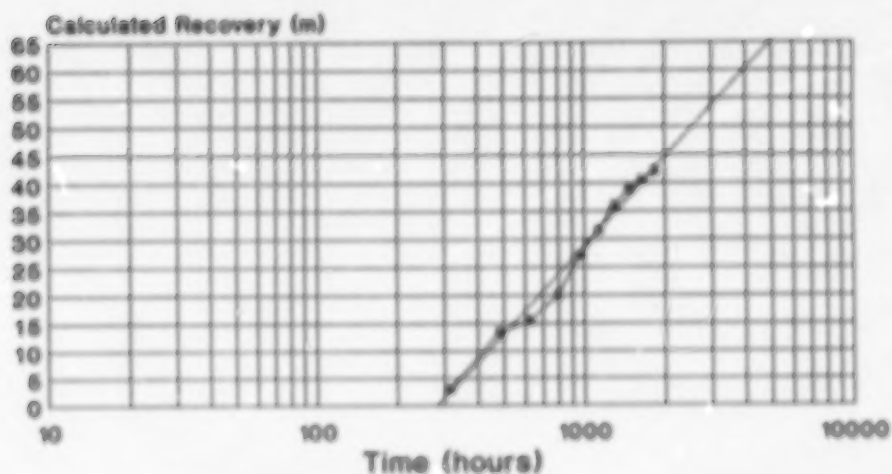


Figure A-5

Recovery data collected for wells ETW-1, ETW-2, ETW-3 and OW-1A during the mine close-out period in 1982 (Leggette, Brashears & Graham, 1983), plotted on semi-log diagrams.

A-12

OW-2
Recovery Data
August 12 - October 27, 1982



OW-3
Recovery Data
August 12 - October 27, 1982

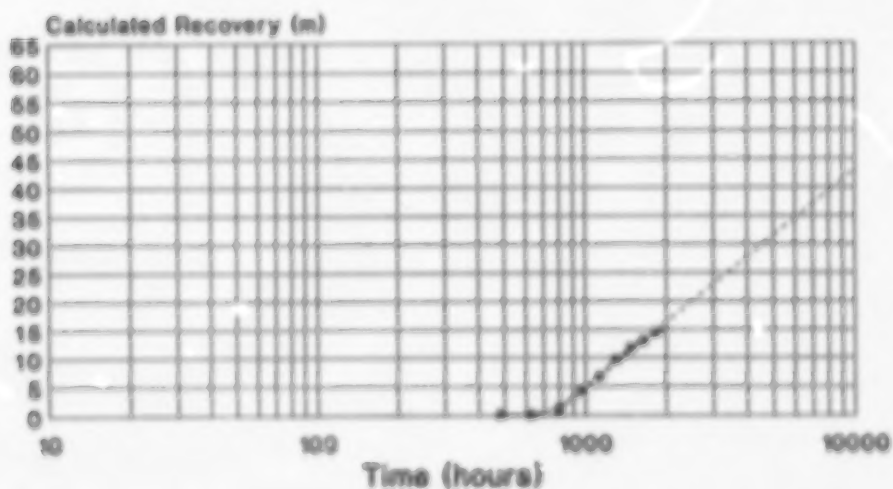
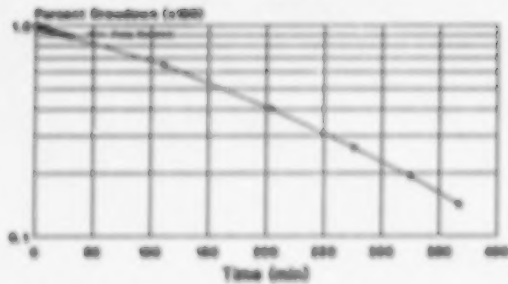


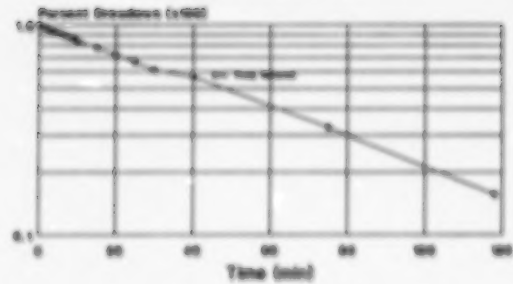
Figure A-6

Recovery data collected for wells OW-2 and OW-3 during the mine close-out period in 1982 (Leggette, Brashears & Graham, 1983), plotted on semi-log diagrams.

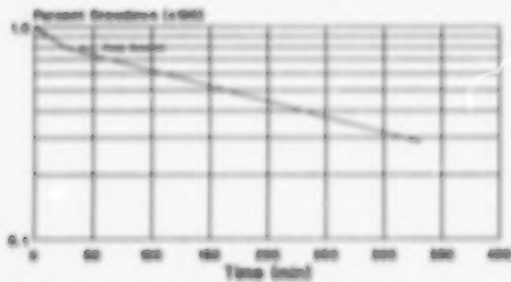
DW-1
Recovery Test
April 10, 1990



DW-2
Recovery Test
April 10, 1990



OW-3
Recovery Test
April 12, 1990



ETW-4
Recovery Test
April 12, 1990

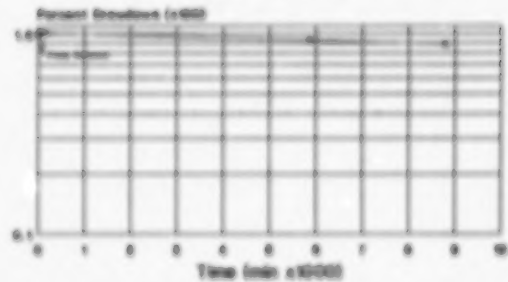


Figure A-7 Recovery data collected for DW-1, DW-2, OW-3, and ETW-4 after pump tests at each well (Lamb, 1990).

APPENDIX B

LARGE SCALE MAPS

B.1 Large Scale Maps

Large-scale working maps have been contoured to show the detailed distribution of hydraulic heads as computed by the groundwater flow model. Contouring the data at the page-size scale has resulted in only approximate representations of hydraulic head. A comparison between figures included with the text and the maps appended here shows that contouring at the map-scale has provided a better representation of the head data around the mine excavations.

The LARGE-REGION MODEL plot shows the configuration of the water table for pre-mining conditions. The SMALL-REGION MODEL plots contour data from the simulation of a low to average mine inflow of 4017 USgpm (i.e. no simulated flood plain, average infiltration). Maps are presented to show the detailed distribution of the water table at surface, and hydraulic heads at the 480 m and 440 m mine levels. These maps are enlarged views of Figures 4-4, 4-5, and 4-6, respectively.

**MAPS
NOT
FILMED**

**CARTES
OMISES**